"Impacts of the Aircraft AM-X´s Acquisition Program (1982-1994) on Technological Capability of Brazilian Aeronautical Industry Leader"

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ABSTRACT

The AM-X Program (1982-1994) was an important military aircraft acquisition program developed with the aim of empowering the development of the Brazilian aeronautical industry. Historically, it is possible to link EMBRAER´s technological path to the defense programs that support it. However, few studies have examined the technological and organizational outcomes that have been achieved by industries that have participated in large governmental programs. So, a retrospective analysis of the negotiation model used in the AM-X program was carried out and of the technological impacts the program had on EMBRAER, from data obtained in field research and from studies about technological development in the sector.

A documentary survey was conducted to analyze the Memorandum of Understanding between Brazil and Italy, the main contracts, other regulations and the documents available in the Coordinating Committee of the Combat Aircraft Program. Open interviews with the Manager of the AM-X program and his team were performed too. We were searching for the general program guidelines and the evidence of its importance for the development of the Brazilian aeronautics industry. From the review of relevant academic literature, the indirect results of the program could be evaluated by the Cabral (1987) model, which allows evaluation of the gains of a technological nature generated by the program. The results emphasized the new processes that Embraer has come to master, especially in manufacturing aerostructures, avionics integration and product engineering. These aspects resulted in production capabilities and innovation capabilities, especially in the design of new aircraft and new technologies.

Key words: Defense Acquisition Program, Brazilian Aeronautics Command, AM-X aircraft, technological capability, EMBRAER

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1. INTRODUCTION

Historically, defense acquisition programs have been used by developed countries to strengthen the aeronautics industry. In the Brazilian case, the AM-X Program (1982-1994) was an important acquisition program developed with the specific aim of leveraging the development of the national aeronautics industry. The program was carried out in partnership with the Italian Ministry of Aeronautics and its aviation industry. Brazil and Italy were the program holders and neither one predominates over the other. Thus, it was possible to operationalize the integration of Brazil, by EMBRAER, to the program that had already been developed in Italy. It was believed that EMBRAER would have a unique opportunity to absorb technological knowledge and to improve its workforce qualification at the international level. The firm could strengthen its capabilities to develop innovations and to compete in global markets with a sustainable competitive advantage. In fact, the long term growth of EMBRAER lead us believe that Brazilian government support has been very relevant to its development. However, there is a scarcity of studies about technological impacts in large defense programs regarding the accumulation of technological capabilities in the aviation industry, especially EMBRAER.

In general, the academic literature about the evaluation of technological investment programs shows that such programs can be evaluated by their direct and indirect impacts. The direct ones refer to program objectives defined in the contracts and the indirect ones, the spinoffs, are new combinations of existing knowledge in the program that overflow into other areas and activities generating positive impacts for the organization as a whole, such as unpredicted products, new technologies, organizational changes, new methods, new techniques, new technological capabilities, etc. The spinoffs are a broader phenomenon than the process of technological transfer and can generate an economic impact as, or more important than the expected innovation (BACH, 1992). According to Furtado *et al* (2008), spinoffs are the result of the learning process, which is derived from the sedimentation of organizations' technological capacities.

Public procurement programs such as military acquisition programs have as an explicit goal the development of defense products. However, the spinoffs generated during the program generate new technological capabilities that are relevant to the technological progress of the country. Evaluation of these indirect results can be performed using the methods of assessment of impacts of large programs developed by the Bureau d'Economie et théorique Apliquée (BETA), which divides the indirect results of a program into four types of impacts: technological impacts, commercial (and competitive) impacts, organizational impacts, and impacts on human resources (BACH, 1992). However, it is difficult to implement in the case of military acquisition, due to the difficulty in obtaining data about the set of impacts to be assessed, taking into account that such impacts occur in firms that develop products purchased. So, if credited these perceived difficulties may explain the scarcity of academic literature devoted to the evaluation of acquisition programs in Brazil.

Considering a restricted scope of review to analyze the development of technological capabilities, the review of the literature presents the model of technological evolution proposed by Cabral (1987) for EMBRAER that seems appropriate to capture the indirect impacts of acquisition programs resulted in the company. The model of Cabral (1987) allows identification of how these impacts have materialized in the accumulation of technological capabilities that enabled the subsequent evolution of EMBRAER. Which coincides with the most relevant objectives of the AM-X Program: causing the development of technological capabilities that could leverage the generation of innovations in firms in the aeronautics industry.

In this context, the aim of this paper is to make a retrospective analysis of the technological impacts that the AM-X Aircraft Acquisition Program caused in the main company of the Brazilian aeronautics industry, using as a foundation the results of field research about the program and the Cabral thesis (1987). From this perspective, it was found, on the one hand, that the AM-X program had satisfactory results to comply with the direct goal of delivering an aircraft in accordance with the technical requirements of Brazilian Ministry of Aeronautics (MAER)[6]. On the other hand, from the review of relevant academic literature, the indirect results could be evaluated by the Cabral (1987) model, which allows evaluation of the gains of a technological nature generated by the program.

A documentary survey was conducted in 2011 to analyze the Memorandum of Understanding between Brazil and Italy, the main contracts, other regulations and the documents available in the central library of the Coordinating Committee of the Combat Aircraft Program (COPAC)[7] and together with the office management of the AM-X program. Open interviews with the Manager of the AM-X program and his team were performed, aiming to raise the general

[6] Currently, the Aeronautical Command.

[7] The COPAC is the executive body in the field of aircraft purchases, subordinate to the Department of Aerospace Science and Technology (DCTA).

program guidelines and the evidence of its importance for the development of the Brazilian aeronautics industry. This article is divided into seven sections, besides this introduction. The second section will present the theoretical framework that underpins this work. The third section will present the results from the characterization of the general outlines of the AM-X program and of Cabral's thesis (1987) which examined the technological trajectory of EMBRAER. The fourth section discusses the importance of the program for development of the national aeronautics industry. Finally, the paper concludes and proposes future work.

2. THE CONCEPTUAL FRAMEWORK

The evaluation method of the impacts of large Research and Development programs developed by *Bureau d'Economie Théorique et Apliquée* (BETA) was initially developed to capture the indirect impacts resulting from major investments that were made in the aerospace sector (BACH, 1992). It was also shown as very suitable for capturing the effects of investments in projects to develop specific technologies in the oil industry (FURTADO et al, 1999). Also in very specific Research and Development projects, like the genetic improvement program PROCANA (HASEGAWA, 2005) and the research and basic sanitation program PROSAB (FURTADO et al, 2008).

BETA analyzes the indirect results of a of technological investment program in four types of impacts: technological impacts, commercial impacts, organizational impacts, and impacts on human resources. Soon, it provides a wide range of variables that can be analyzed in evaluation models for the impacts of large programs. The technological impacts refer to the transfer of knowledge that was not originally expected (new products, new processes, technological services, patents). Commercial impacts analyze network impacts from the relationships between participants (collaboration links after the project, reputational impacts, from the largest project recognition and external visibility, quality certificate); and competitive impacts resulting from new partnerships and opportunities because of project learning. The organizational and method impacts refer to marks that the project has left on the culture of the organization and organizational structure (skill in managing projects, changes in organizational structure, implementing quality and research and development departments, new methods that are transferred to other activities). And the impacts on human resources relate to new contracting that were made during the projects and the specific training administered, beyond the learning processes during the execution of the project. (BACH, 1992)

Furtado *et al* (2008) and Lima and Urbina (2009) help us to understand that it is possible to evaluate the programs through their impacts that are manifested such as the creation and strengthening of technical, organizational and technological capabilities. In the case of programs of a technological nature, technological capabilities created and developed by the program are a key aspect to evaluate the investment realized. Hasegawa (2005) goes further and analyzes the process of spinoffs creation and shifts attention to the intermediate results that are created by the program. These interim results are precisely those generated capabilities that make spinoffs possible.

Hasegawa (2005) provides a typology of capability.[8] 1) Organizational capability: capability of the institution to organize internally in a way to optimize the learning process, deepen internal knowledge base and still be able to make changes. 2) Relational capability: ability to establish and maintain contacts with external actors to inter-act, learn collectively and exchange tangible and intangible assets. It includes the ability to disseminate knowledge, to choose partners *know-who*, to encode *know-who* and to gain visibility and reputation. 3) Scientific and technological capability: ability to use scientific and technological knowledge to assimilate, use, adapt, and change existing technologies; and to develop new technologies, products and processes. It also includes the absorption capability (ability to absorb external knowledge and use it for the benefit of the company). This categorization approaches the functions of the Matrix Technology Capability of Lall (1992)[9] and differs because it includes an organizational function.

The construction of the technological capabilities of firms in lately industrialized countries involves a deliberate process of acquiring knowledge and skills, which can configure a

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[8] Hasegawa (2005) makes no distinction between the terms capability and capacities and even uses the term as a synonym for competence. Lima and Urbina (2009) also developed, from Hasegawa (2005), a method for the evaluation of capability for the management of innovation projects.

[9]Lall (1992) based on Katz (1984 and 1987), Dahlman, Ross-Larson and Westphal (1987) and Lall (1987) presented an illustrative matrix of main technical functions that a firm would need to master to be categorized into a certain level of technological capability and advance towards the frontier of innovation. These pioneering works elapsed many others among Brazilian authors include Figueiredo (2002, 2003a, 2003b, 2004, 2005, 2008 and 2014), Oliveira (2005) and Silva (2009).

KATZ , J. (1984) "Domestic technological innovation and dynamic comparative advantage: Futher reflections on a comparative case study program", Journal of Development Economics, 16 (1): 13-38.

KATZ , J. (1987) "Domestic technology generation in LDCs : A review of research findings", In KATZ, J. (ORG) Technology Generation in Latin America Manufacturing Industries, New York: St Martin's Press.

Dahlman, C.; ROSS-LARSON, B.; WESTPHAL, L. E. (1987) "Managing technological development: Lessons from Newly industrializing Countries", World Development, 15 (6): 759-775.

Lall, S. (1987) Learning to Industrialize: the Acquisition of Technological Capability by India. London: Macmillan.

very critical task for these firms, since they started their activities from imported technology. The acquisition of equipment abroad does not incorporate technological knowledge and knowledge transfer arising from it is not explicit in their instructions or patents. In this scenario, questions relating to the learning process bound for the international technological frontier process are reinforced. Technological learning is an intrinsically evolutionary and cumulative process and can only be developed at the local level. (LALL, 1992, LEE, 2000; TEECE, 2000; FIGUEIREDO, 2004 and ROSSITZA, 2008)

According to Figueiredo (2014), the accumulation of technological capabilities generates benefits within the firm that translate into inventive or innovative activities, in improving operational parameters and competitive performance, and in creating standards of corporate growth. “The technological capabilities are understood as a stock, a reservoir of resources that allows the firm to perform activities of both production and innovation, and of innovation in different degrees.”[10] The ability of the firm to implement an innovation reflects the nature and depth of its technological capabilities. Such capabilities enable innovation, and are not always a direct result of R&D activities (FIGUEIREDO, 2003 and 2014). The concept of technological capability refers to the accumulation of knowledge to generate capabilities that are accumulated and incorporated in individuals and organizational systems, following the theoretical approach of Bell and Pavitt (1993). It is intrinsically related to internal efforts to adapt and improve imported technology (FIGUEIREDO, 2004 and 2003). And to create something entirely new – accumulation of innovative capabilities (FIGUEIREDO, 2014).

This theoretical framework done, it is possible to build bridges with Cabral’s evaluation method (1987), which searched within EMBRAER, its technical and production departments, technical capabilities that were created and deepened due to the participation in programs for acquisition of military aircraft.[11] Cabral (1987) constructed technological development model for EMBRAER from identifying its technologically relevant areas. He also identified the technical gains incorporated into products for aircraft models produced. Thus, Cabral (1987) inaugurated an entirely new field of research in Brazil, which did not continue. In fact, it is observed that the available literature about the first major programs that Embraer was involved in are of a historical

[10] This definition was given by Professor Paulo N. Figueiredo (FGV / RJ) in the qualifying examination for the Ph.D. of the first author of this article, at ITA, 12/12/2013.
[11] Cabral (1987) analyzed these models: Ipanema, Bandeirante, Xingu, Xavante, AM-X, Tucano, Brasília, AM-X and EMB-123.

and economic-financial nature, without the concern for evaluating the topics relevant to the technological point of view (modifications of the production process in the development or improvement of an aeronautical product).

The author's work shows that EMBRAER is a "counter- example of a state-owned third world company", that was able to make significant changes in its products throughout its existence (CABRAL, 1987, p. 5). The technical evolution was perceived as the way in which inputs are transformed into outputs, including the improvement of the product, in other words, the "set of major technical changes that the firm absorbed and used on its aircraft" (Cabral, 1987 p. 12). Cabral’s results (1987) will be analyzed in detail in the next section. It is noteworthy that the work of Cabral (1987) is within the scope of evolutionary theory or neo-Schumpeterian, which takes the firm as a complex institution and analyzes from all its available resources, including technology. Such an approach is a critique of neoclassical theory, which sees the firm as a "black box" that reacts mechanically to its environment.[12]

3. RESTROSPECTIVE EVALUATION

This section will present a retrospective review of the AM-X Program. The general program guidelines, the reality of the aircraft industry and the technological capability program will be presented. In the following subsections, the impacts of the AM-X program in the process of the accumulation of EMBRAER’s technological capabilities and techniques will be described.

3.1 Negotiation Model

The AM-X aircraft Acquisition Program emerged from the need of MAER to equip the Brazilian Air Force with equipment capable of operating at extremely low altitudes by day and night and in poor visibility, on semi-prepared runways, in long-range missions, which were the conditions under which the aircraft would have to perform in Brazil, and for the aircraft to be capable of flying in a damaged condition. It had to be an attack aircraft that would give tactical support to ground Forces, aerial reconnaisasance and armed recognition in all weather conditions. However, there was no production in Brazil of an aircraft that would meet these requirements in the late 1970s and early 1980s. EMBRAER then initiated a search for partners in the United

[12] PENROSE E.T. (1959) The Theory of the Growth of the Firm. New York: Oxford University Press; FREEMAN, C. (1982) The Economics of Industrial Innovation. Londres: Frances Pinter; ROSENBERG, N. (1982) Inside the Black Box: Technological and Economics. Cambridge UP.

Kingdom and Italy to develop an aircraft that would meet the needs of MAER. EMBRAER had a good partnership with Aermacchi in the Xavante project and this relationship opened the doors to the possibility of participation in a project that was in progress in Italy in partnership with Aeritalia, the AM-X Project. (OZIRES SILVA, 1998)

The Declaration of Principles on March 21, 1980 stated the Brazilian government's desire to participate in the AM-X program already underway in Italy. The Basic Agreement of Technical Cooperation between Brazil and Italy in 1972, promulgated by Decree 84,967 of July 23, 1980, established the basis for partnership cooperation in terms of economic and social development goals. The technical cooperation would include the transfer, in the broadest sense of the term, knowledge and experience, which could be accompanied by material aid (Article I, item 2, of the Basic Agreement of Technical Cooperation). The cooperation included a provision for technicians to provide advisory and executive services, the provision of scholarships and improvement, the supply of machinery and equipment necessary for the implementation of the project and any other type of material support that was agreed. Decree 84,967 (Article VIII) also established that the equipment and materials needed for the technical execution of tasks and projects related to long term projects would be exempted from prior import permit, certificate of foreign exchange coverage, consular fees, taxes on acquisition consumption and sale, customs duties, import duties and any other taxes, excluding storage and other similar costs.

The strategic management and project management of the development and production of the AM-X aircraft, in all its phases, sub-phases and activities, was agreed in a Memorandum of Understanding between Italy and Brazil. The program was divided into the following phases: Definition Phase (stages 1 and 2), the Development Phase (1st sub-phase, 2nd sub-phase, 3rd sub-phase, acquisition license for the SPEY MK-807 engine and extending the reproduction rights to Brazil), Industrialization Activities and the start of the production cell, Production Phase (production of aircraft batches: 1st, 2nd and 3rd batches), the Employment Support Phase (updating activities for the configuration of batches) and Post-Development Activities.

Aeritalia and Aermacchi were the main companies that participated in Italy and EMBRAER was the company that participated in Brazil. Aeritalia, which later became known as Alenia, assumed the function of the main company responsible for managing contracts with the Italian Air Force. Aermacchi and Embraer participated in the joint procurement as associated companies. In 1981, MAER promoted the first program agreement, which was the contract of industrial integration of EMBRAER to the AMX program that was underway in Italy. National contracts for aircraft production between Costarmaereo, Aeritalia and Aermacchi were established by the Italian party; and for engine production between Costarmaereo, Rolls Royce, Fiat Aviazione, Alfa Romeo Avio and Rinaldo Piaggio.

The Brazilian part was established by contracts between MAER, Aeritalia, Aermacchi and Embraer, for production of the aircraft; and for the production of engines between MAER, Rolls-Royce, Fiat Aviazione (the offers by Alfa Romeo, Avio and Rinaldo Piaggio were presented by Fiat) and Celma. The companies responsible for engines developed their activities based on the Industrial Cooperation Agreement of 1986, in which Fiat Aviazione was responsible for coordination and control, according to the license agreements for the production of engines. Costarmaereo contracted Rolls-Royce for the acquisition of complete kits and spare parts; and Fiat, for the adaptation of drawings, tooling for performing final assembly, testing, long-term materials supply, etc. The same activities were planned for the contracts between MAER, Rolls-Royce, Fiat and Celma.

The AM-X program was executed through joint contracts and national contracts. The joint contracts established joint activities with joint funding. The national contracts established non-common activities, each responsible party assuming payment for their part regardless of where the work was carried out. The general criteria that guided the participation of each industry (use of industrial capacity and cost sharing) in the program were based on the number of aircraft each country was acquiring: of the total of 266 aircraft, 187 were destined for Italy, and 79 for Brazil, the resulting proportion being 70.3% for Italy and 29.7% for Brazil. The principle of single-source supplying of components and sub-assemblies for production was also established. The same industry was responsible for providing materials and equipment for both involved countries and the industrial capacity of enterprises should be used up to the stipulated percentage. The total production of an AM-X aircraft was divided according to the proportions noted in Tables 1, 2 and 3. Embraer was responsible for the production of the wings; Aeritalia was responsible for production of the central fuselage, and Aermacchi was responsible for production of the upper fuselage.

Table 1. Percentage of EMBRAER Production

EMBRAER	WINGS
Wings	16,8%
Air intakes	1,0%
Slats	1,6%
Flaps	2,3%
4 Pylons	3,7%
4 sublares tanks	4,3%
Total	29,7%

Source: Prepared from the Memorandum of Understanding between Brazil and Italy.

Table 2. Percentage of AERITALIA Production

AERITALIA/ALENIA	CENTRAL FUSELAGE
Front fuselage	8,8%
Central fuselage	28,2%
Ailerons	0,8%
Spoilers	1,35%
Horizontal stabilizer	3,3%
Vertical stabilizer	2,5%
Twin carriers	1,6%
Total	46,5%

Source: Prepared from the Memorandum of Understanding between Brazil and Italy.

Table 3. Percentage of AERMACCHI Production

AERMACCHI	FUSELAGEM SUPERIOR
Upper Fuselage	19,5%
Lower Fuselage	4,3%
Total	23,8%

Source: Prepared from the Memorandum of Understanding between Brazil and Italy.

3.2 The Reality of Brazilian Industry and the Technological Capability Program in the AM-X Program years:

EMBRAER was founded in 1969, from the technological capabilities developed at the Aerospace Technical Center (CTA).[13] This process of creating technological capabilities followed developmental inductive logic, a *top dow* style of policy in which the State planned and contributed to the implementation of an aircraft industry in Brazil. The CTA concentrated a large number of independent institutes that promoted diversification in developing technological capabilities. It created the necessary conditions for the development of domestic aircraft industry synergies.[14] CTA was linked to MAER, which was an important because it reduced the degree of uncertainty among stakeholders and enabled the establishment of a network of trust that extrapolated the relationship between the institutes. (OLIVEIRA, 2005)

In the context of development of the Brazilian Aeronautics chain, it had the Complementary Industrialization Program (PIC) that aimed to promote the company's industrial capability for the production of the AM-X. It was expected that preselected firms would become capable of producing strategic items, in order to generate alternative sources of supply in the future. In relation to direct suppliers, according to Cabral (1987), EMBRAER, in the manufacturing area, produced highly complex machined parts and subcontracted to other national companies the manufacturing of low complexity machined parts.

The program directly benefited EMBRAER as, in 1981, the first contract for EMBRAER's own training was signed, especially in matters of planning and execution of its increasing technological capability, since the company, in Brazil and abroad, was responsible for the definition, search, selection and purchase, on behalf of the Brazilian government. In 1986, the second industrial capability contract was signed. This agreement aimed at the capability for the execution of the remaining activities of the development phase and production activities, as well as the acquisition of training equipment and equipment indispensable for landing gear industrialization.

The PIC contracts date from 1987 and EMBRAER was responsible for managing the growth of industrial resources of Brazilian companies. The firms that participated were technically qualified and held licenses to manufacture aeronautical equipment in Brazil, under the

[13] Currently, DCTA.

[14] Other companies have emerged from the same conceptual logical: Avibrás Aerospace SA (1961), Forteplas (1962), Decorec (1963) and Engesa (1974), according to Souza (2008).

technical management of Embraer, or who would be able to obtain a license for domestic production. The “package” of capability consisted of training activities for technical staff, purchase of machinery, production equipment, testing equipment, laboratory, special tools, technology services, technical assistance and specific training for the industrialization of the landing gear and hydraulic equipment. A management contract for PIC was also established. The licensed firms (companies that received production licenses) were responsible for: promoting along with the government, contact with foreign licensed companies (companies that granted the license); to issue drafts of license agreements; to carry out definitive agreements, under terms accepted by the government; to sign in association with the government the training contract; to sign in association with EMBRAER the supply contract; to absorb the technology and to manufacture equipment.

Nine firms participated in the PIC: Elebra, Aeroeletronica, Microlab, Engetronica, Pirelli, Celma, ABC Systems, TECNASA and Engesa. The firms which were secondarily contracted by EMBRAER could not be identified from the documents of the Air Force Command, which presented a limiting factor to the research.

3.2 Importance of the AM-X Program for the Accumulation of EMBRAER’s Technological Capabilities

Cabral (1987) analyzed the departments that were linked to the development of aerospace technology and its absorption within the company, which were the Technical Department and Production Department. The scope inside these departments was limited to the divisions that were involved in the design and manufacturing stages, which made up a crucial part of the process of technological innovation in the company. Eight key technology areas were selected from the field research (consulting experts, company visits, questionnaires and reading of technical reports): aerodynamics, structures, materials, product engineering, avionics, flight controls, flight tests (all of them in the Technical Department) and manufacturing (Production Department). These areas were representative of the majority of the technological efforts made by Embraer.

The main technological impacts resulting from participation in the AM-X program on the evolution of EMBRAER’s technological trajectory reflected in these areas: manufacturing, avionics, product engineering, aerodynamics, materials, flight controls and flight tests. We devote more time to the presentation of the results of Cabral’s thesis (1987) for the manufacturing area, because there is a good presentation of the change in industrial processes during the AM-X Program. The industrial manufacturing processes were intrinsically related to the types of machines that were being used, so that the change in machinery entailed a significant change in industrial processes. In the cutting of sheet metal parts at the manufacturing stage, it moved from the use of conventional Routing machines (contornadeiras) to the use of numerically controlled Trumpf Routing machinery. With the former machines, the end plates were cut into rectanglular shape. The latter machines dispensed with the cut into rectangles and manual operation. As they were connected to computers, the Trumpf Router electronically recognized the format of the pieces and made the best arrangement of the different parts for cutting the whole plate. The forming step was carried out by means of presses (estiadeiras) and chemical milling, and at the end there was still a lot of manual work for the platers. The technological evolution in this area was marked by the type of machine that was being used and the knowledge necessary for its operation.

The manufacturing of machined parts was made by removal of material and chips. The evolution of parts occurred in the number of parts used and the complexity of the shape. The Ipanema aircraft was built entirely of panels and tubes, so that there were no machined parts. In later models, primarily, the machining was performed by conventional type lathes, milling machines and milling machine copiers. The simplest parts were ordered from other companies and the most complex were produced by Embraer through milling copiers (which had a template to copy) and then by digitally controlled milling machines with great impact on the cutting system and the quality control processes. The great evolution occurred through the arrival of machines programmed to use CAD-CAM (Computer Aided Design - Computer Aided Manufacturing), which is a technology that allows the construction of flat or three-dimensional geometric entities and simulation of manufacturing conditions. Many digitally controlled machines were purchased in 1983, the Grantry's with five axles and multi-spindles allowing different movements. The AM-X aircraft was almost completely manufactured from parts with complex shapes and reduced tolerances.

The evolution of the production of composite material[15] occurred through the passing from manual impregnation without any concern about weight or strength of the part and natural curing, to the use of a vacuum system. In the 1980s, the system of production of composite material was the cutting-edge technology, being a pre-impregnated system with autoclave curing. The benefits were huge in relation to the weight of the part, strength, quality and manufacturing time, and there were immediate effects on the organization of industrial processes.

The evolution of metalworking, at the welding stage, occurred through the training of skilled personnel for the operation of nonstructural welders used to weld aluminum alloys in an argon atmosphere, as well as the use of electric welding for aluminum, titanium and copper alloys. The evolution of the bonding step occurred in structural bonding, applied to vital structural parts for the aircraft, such as the flap, by epoxy adhesives in the form of already impregnated films. Parts manufactured with structural bonding were 25% lighter than parts manufactured by the conventional process.

The evolution of assembly went from the line format to the “U” format, with support teams on both sides with access to the aircraft, which facilitated communication between the components of the assembly stations. The final assembly process was also changed from final assembly by system to final assembly by station. The assembly line, which was coordinated by the system manager, and who supervised it to completion with his team of professionals, changed to be composed of eleven stations, each of which had all the professionals needed to perform a given task. In this way the waiting time and the competition between groups for error detection was reduced. There was also an evolution towards the use of different materials, because different types of pipes, hoses, wiring and control cables required different forms of installation and staff training.

In the control quality area, evolution also occurred as to the machines that were acquired. In the beginning, traditional inspection equipment such as calipers, voltmeter, micrometer, mechanical scales, hardness and tensile machines were used. In the 1980s, sophisticated digitally controlled machines and new computers for inspection were acquired. In 1987, the Directorate of Quality Assurance was created, as previously there was only a division within the Technical Department, which shows the growing importance of this sector in the company.

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[15] Merging of two or more elements with different properties, in order to manufacture a third element that retains the characteristics of its constituents. (CABRAL, 1987)

Between 1982 (the end of the development of the Brasília) and 1986, the highest level of investment in manufacturing and quality control was found. In 1986, Embraer simultaneously produced five models of aircraft: the Bandeirante, Xingu, Tucano, Brasilia and AM-X. This considerably increased the number of employees in manufacturing, particularly in the Process Division, which was part of the Production Department. In 1979, there were seven engineers in this division; in 1986 there were seventy three engineers. There was also an increase in the area built for manufacturing activities. It was also possible to observe gains in time in the assembly area (manual tasks), although such gains in manufacturing tasks were not relevant.

In the avionics area, advances were notable and even pioneered in Europe, from the use of the *digital serial* data transmission system based on the American standard. In the 1960s, there were a large quantity of small electromechanical clocks on the control panel of a typical aircraft. In the 1980s, we had the revolution of the instrumentation on board by the full adoption of digital data transmission systems, which was made possible by the introduction of Cathode Ray Tubes (small on-board TVs). The Bandeirante was the first aircraft which used a more complex avionics system. In the Brasilia aircraft a reasonable qualitative leap in the avionics system was observed, such as the newest generation of digital autopilot, which coincided with the introduction of Cathode Ray Tubes. In the AM-X fighter, advances were significant because of the use of a digital transmission system.

Advances in avionics were verified from the introduction of new equipment in the final product and were not broken down at the level of modification of industrial processes. However, Cabral (1987) characterized the avionics area, according to the technological steps learned in the product area, as a project importer (designs and process); as a copier of imported technology and adapter/modifier for different ends. It can be concluded that these levels of learning had in themselves essential elements for building technological capabilities in the area of avionics, with great importance for further development of the company. It was the area of greatest technological development and greater technological capability for EMBRAER, in which was found an intensification of the search for technical knowledge. At the beginning of Brasilia production, there were ten people working in the area; with the AM-X that number increased to sixty specialists, many of whom were trained in Italy and worked directly in the program abroad. This training prepared EMBRAER for the future challenges of commercial aviation.

In the area of product engineering, before the Brasilia and AM-X, this division worked with clipboards, tracing paper, drawing boards and glass tables for photo tracing. With these aircraft, the introduction of CAD-CAM (Computer Aided Design-Computer Aided Manufacturing) significantly altered this context. CAD-CAM allowed a direct dialogue between the designer and the machine, as parts were designed and manufactured with greater precision and quality. CAD enabled a breakthrough in the drawing of electrical systems, automatic testing and the consistency of cabling. There was an increase in the area built for this purpose and of the drawing file area. There was also a greater specialization of manual labor in the sector. Cabral (1987) characterized the product engineering area according to the technological learning stages in the product area, as a provider of original design in the same operational and market area; as an adapter and copier of imported technology. It can be concluded that these levels of learning were very relevant for the development of technological capabilities in the area.

In the aerodynamics area, evolution came about from the generation of appropriate profiles (joint of the wing with the fuselage) in the development phases of the project. At the beginning of EMBRAER, NACA profiles (later NASA) were used that were public domain profiles. At the time of the AM-X, the intensive use of computational work allowed the calculation of features for profiles with higher speeds. In relation to performance calculation for the AM-X model three dimensions were incorporated: the theoretical, from the estimate of drag force;[16] generating aerodynamic coefficients calculated by wind-tunnel and calculation obtained by way of flight tests.

In the materials area, evolution occurred through the use of Alclad plates (copper-aluminum alloy coated with pure aluminum) with autoclave curing at 180°. Aclad plates had already been used; the difference was in relation to the curing process. In this area, the evolution was much more significant in the Brasilia aircraft. Cabral (1987) characterized the materials area, according to the learning stages in the context of methodology, as an importer of technology and dominator of technology at the operational level.

In the area of flight controls, technological advance created the need to develop a command that would capture artificially the sensitivity that the pilot no longer had to use for deflecting the rudder (servo-hydraulic systems). Thus, the Fly-by-Wire system was developed for

[16] Permit verification if the targets are being reached.

the AM-X aircraft, whose signals and respective actuation were electric: flap, rudder, stabilizer, spoiler and slat.

In the area of flight testing, the AM-X aircraft needed sophisticated tests because of the systems installed in the plane (inertial navigation system with accuracy check and photographic reconnaissance system). It was necessary to do flight quality tests (stability and control) and performance with dynamic maneuvers (calculation of aerodynamic parameters in flight maneuvers). The need to use various pieces of equipment created the environment for training a very select group of people within the company, in addition to employing new engineers in the area. The AM-X was the most demanding aircraft to be tested. Investments in equipment increased with the Brasilia and AM-X. Cabral (1987) characterized the area of flight-testing, according to the stages of learning in the context of the methods as a copier of imported technology and adapter/modifier for different ends.

According to Cabral (1987), the development of the Brasilia aircraft and AMX fighter constituted the greatest technological challenges for EMBRAER, since designing and building these models raised the technological level of the company; and constituted the pillars of knowledge that enabled subsequent developments in civil aviation organization.

4. DISCUSSION

The experience of the AM-X Program represented a time in Brazilian history, in which the State concentrated financial and technological efforts in the joint development of a military aircraft with the effective involvement of national industry. EMBRAER was greatly benefitted by the program and was responsible for the training activities of other national companies. It was a program of employment for national industry, driven by MAER, which was beyond what a contract based on *Offset* could offer.[17] Miranda (2008) emphasizes that the signings that involved product development favor the development of the ability to modify technologies and to find new solutions. The experience of the U.S.A. also demonstrated that the main instrument for promoting the national aircraft industry was the preference for the purchase of domestically produced goods.

Cabral (1987) presented several technical gains that employment in the AM-X program allowed for EMBRAER: procurement of equipment, modernization of company structures and

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[17] *"(...) Any compensatory practice agreed between the parties as a condition to import goods and services, with the intention of generating industrial, technological and commercial benefits."* (DCA 360-1 (2005, p. 10).

laboratories, use of new software and systems in design, which drastically altered the way of working, the consolidation of a skilled workforce in tune with what was happening in the technological frontier of the international aviation industry. The program also included a very important aspect of neo-Schumpeterian literature on technological capabilities: direct involvement in the firm's development and production activities at the local level.

Santos (2004) also identified the program as a major lever for the generation of knowledge at Embraer. The interviews carried out suggested that cooperation was an atypical and precise process, and aimed to promote direct benefit to the industries of the two countries. The program was seen as a milestone in the technology program model that had to be recovered.

The program made it possible principally for EMBRAER to acquire cutting-edge knowledge, representing a program of technology transfer and shared creation of new technology. In this way, this favored the development of technological capabilities that allowed the leading firm to innovate.

Currently (2014), the reality of the Brazilian aeronautical industry is oriented according to the sharing of risk with its partners abroad, which on one side confers numerous benefits to the domestic partner company in reducing the risks involved in contracts, access to new markets and transfer of technology. However, in the long term, this Model of Systems Integration (CHAGAS JR., 2005) based on internationalization does not address the strategic national issues of the defense sector, particularly with regard to the development of its Industrial Base.

5. CONCLUSION

The AM-X Program greatly increased EMBRAER’s knowledge in technological areas relevant to its development. It was important to outline the current logic chain (introduction of the logic of integration and risk-sharing partners). According to Ozires Silva (1998), the program cannot be considered exclusively as a program of technology transfer, because much of what was done was designed and specified for the first time jointly, the solutions applied were innovative and were not based on an existing installation.

Cabral (1987) emphasized the new processes that Embraer has mastered, especially in manufacturing aero-structures, avionics integration and product engineering. These aspects resulted in production capabilities and innovation capabilities, especially in the design of new aircraft and new technologies. The program was directed towards the accumulation of technological capabilities for EMBRAER, since it combined the development of capabilities that concentrated a certain degree of innovation for the company. This process of accumulation of technological capabilities was sustained by targeted efforts within the company and by explicit learning mechanisms. EMBRAER forced itself to reach more advanced technological levels. It can be stated that the program was not primarily a program for importation of technology but a technological modernization program involving local efforts to develop new technological knowledge.

One complementary work could be to present how the Defense Acquisition System of the United States of America was structured to promote the expansion and development of its defense industry. Thus, recommendations can be proposed to align the strategic component of military purchases to a directive to encourage the national aviation industry and the development of a set of technological capabilities to promote autonomy and national sovereignty policy purchases.

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