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THE AEROSPACE INDUSTRY IN MEXICO: CHARACTERISTICS AND CHALLENGES IN SONORA

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Abstract

The objective of this paper is to expand the body of knowledge about the situation of and challenges facing the aerospace industry in the state of Sonora, Mexico. To do so, various interviews were conducted with company officials who shared results like the following: the industry has moved toward districts that offer the best conditions to operate; the march of technological flexibility in processes calls for a review of how institutions of higher education in the state are training human capital. Moreover, despite ranking in the country's top five states in aerospace production, the integration of productive value chains still leaves much to be desired, and is concentrated at Level 2 of the supply chains.

Keywords: High-tech industries; productive processes; supply and value chains; technological innovation; training; skilled labor.

1. INTRODUCTION

The aerospace industry is one of the most important and complex in the world. The nature of what the industry entails demands technological innovation as well as the continuous training of its workforce. It also requires great awareness of the production processes found in this industry upon which human lives depend.

According to the National Strategic Aerospace Program (Secretaría de Economía, 2012), this industry's global value chain is divided in various segments: aircrafts and their parts; aircraft engines and their parts; avionic and electrical-electronic systems; maintenance, repair and overhaul (MRO); simulators and training; armaments, space, etc.

The high level of technological sophistication, which is apparent in the final product and not necessarily in the making of easily manufactured small parts, has resulted in these segments being sent to a variety of locales around the world, sites which have fostered and created the conditions necessary to undertake and develop this manufacturing process.

The main goal of this article is to analyze the situation, the characteristics and challenges posed by the aerospace industry in the Mexican state of Sonora within the national context of said industry. Towards these goals the article has been divided in various sections: introduction, the listing and description of the theoretical and conceptual elements which allow analysis and understanding of the development of the aerospace industry; the primary traits which characterize this industry at the global capitalism level and its environment at the state and national levels; a description of the methodology used and finally, the results. The work ends with the conclusions, sources used, and an appendix of individuals and businesses interviewed.

2. THEORETICAL AND CONCEPTUAL FRAMEWORK REFERENCES

Aerospace is one of the leading enterprises of the industrial sector, providing products and transportation, communication, safety and defense services (Morán and Mayo, 2013, p. 3-4). To this end, through the process of globalization, aerospace has settled in various locales, giving way to "the modification of local geography of the manufacturing industry, bringing together a unique space in the global market and a wide array of diverse places dedicated to production across the surface of the Earth" (Boisier, 2014, p. 23).

This meeting of the global and the local has been further emphasized in the last three decades by the liberalization of economies and their formalization in economic integration treaties such as the one uniting all of North America (NAFTA). The seed that gave birth to the centripetal movement is the flexible integrated production processes that Coriat (1992) described as product, range, elements, shipping and volume, which are highlighted in the sense that production processes are complex and impose new ways of connecting work and capital.

The tendency is for globalized companies to move ever smaller parts of their production chain to emerging countries where they are carried out by workers who have a knowledge of and control over the productive processes. This is especially true in high-tech industries like aerospace where workers (in this case in various parts of Sonora) can receive training via traditional means and communication technologies, as well as the means mentioned by Baldwin (2016), tele-robotics and telepresence. In a world moving into the fourth industrial revolution (Schwab, 2016), marked by the convergence of information and communication technologies and industry in terms of the industry 4.0's platform (Hermann et al., 2016), this allows the passing on of knowledge and ideas, retrieving collective knowledge as well as that which comes from experience and expertise in production[2] .

The concept of the fourth industrial revolution, which originally comes from Germany in 2011 and marks a milestone in the technological race, is founded on six design principles: interoperability, virtualization, decentralization, real-time capability, service orientation, and modularity; and four key components: Cyber-Physical Systems, Internet of Things (IoT), Internet of Services (IoS), and the Smart Factory (Hermann et al., 2015).

The working of these principles and components is dependent upon the development of IoT and IoS, as well as of additive manufacturing (3D printing). The reference of the industry 4.0 platform (Cluster Institute. *Industria 4.0*) has the objective of clarifying for the record the trends to which technological advances, such as those of aerospace, are leading

us. This is not to say that these practices are homogeneously distributed within said industry, quite the contrary. They actually form part of a dynamic of "creative destruction" which advances at different levels and rhythms[3] .

As the international economy evolved towards globalization, theoretical constructions arose and in turn became references which are mandatory for this kind of study. This is how Porter (2000) makes an analytic jump when, in the analysis of how to be competitive, he defines the concept of value by saying: "value is the amount buyers are willing to pay for what a firm provides them", a statement he later complements with the concept of value chains, which he defines as "an interdependent system or network of activities" (Porter, 1985). He thereby divides activities into two levels of importance: ones which dominate primary activities which include internal logistics, operations, external logistics, marketing, sales and supply; the secondary ones are support activities and form part of the company's infrastructure, managing human resources, technological development and supply (Porter and Millar, 1985).

Furthermore, we add the concept of supply chains, repeatedly used in the aerospace industry, which are defined as "the activities carried out by each point or series of actors in order to achieve the result of reliable and timely delivery of quality products at a low cost"[4] (Srinivasan *et al.,* 2011, p. 262).

As a corollary to this ensemble of theoretical instruments used to understand the aerospace industry, we refer to the works of another specialist:

> A commodity chain refers to the wide range of activities involved in the design, production, and commercialization of a product[...]the commodity chains aimed at producers are those in which large manufacturers, commonly transnational, play a central role in coordinating production networks (including links forward and backward along the chain). This is characteristic of technology intensive and capital industries, such as the automotive, airplane, computer, semi-conductor and heavy machinery industries (Gereffy, 2001, p. 14).

The contribution which substantiates to this author's approach is related to the internationalization of production chains via networks established between mother companies and micro, medium, and large companies which "help" weave together the different areas of production in order to achieve the final product.

The concepts taken into consideration, the aerospace industry, localities/regions and globalization, flexible productive processes and supply and value chains in each area of the global production chain, are key to understanding the organizational dynamic of the companies which relocate their business processes in an effort to weave their productive processes across the globe together to create a cohesive whole. Said processes are being buttressed by the technological logic surrounding globalization and the advances in tele-robotics and telepresence, and sheltered by the industry 4.0 platform which currently finds itself in expansion.

3. CONTEXTUAL ELEMENTS

The Aerospace Industry at a Global Scale

The development of the global industry forms part of the international division of labor, where countries tend to specialize in accordance to the level of capital they possess, their technological development, how far their production networks reach around the globe and the segmentation of their productive value chains.

The companies with these strengths at the level of the global economy are: Boeing from the US with 7.4% of the global market; followed by EADS in Europe with a 6.5% share, Lockheed Martin Corporation, also from the US, with 4.9% and BAE Systems PLC from the UK with 3.8% of the world market (Clearwater Corporate Finance LLP, 2010, quoted in Morán and Mayo, 2013, p. 4).

The most important conglomerates in the aerospace industry are in Washington (Boeing), California (Boeing, Lockheed Martin, etc.) in the United States; in Montreal, Canada (Bombardier, Pratt & Whitney Canada); in Toulouse, France (Arianespace/Astrium/Airbus/EADS); and in Hamburg, Germany (Airbus/EADS) as well as in São José dos Campos, Brazil, where the Brazilian Company Embraer has its headquarters. Specifically, the leading companies in the manufacture of airplanes are: Airbus, Boeing, Bombardier, Embraer and ATR (Morán and Mayo, 2013, p. 7-8).

From their headquarters, these industrial groupings spread to other countries, regions and localities which offer the appropriate conditions for establishing themselves, conditions such as: infrastructure for relocation, government incentives; trained human resources; educational and research institutions to provide a renewable and qualified work force; companies which guarantee centralized production processes without the distractions of legal and economic concerns; transportation, security and supply; in other words places which conduct outsourcing activities.

The Aerospace Industry in Mexico

The 1990s marked the beginning of the aerospace industry which has shown a noticeable growth in the 21st century (see Table 1), and whose future forecasts boast rising investments, companies and jobs until 2020.

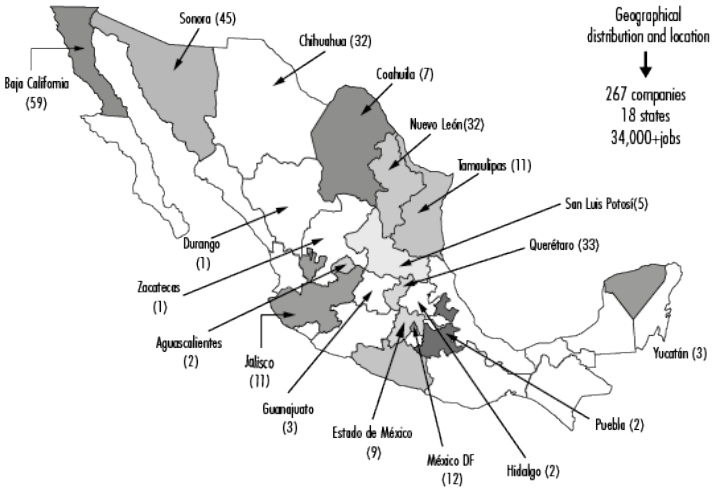
Table 1. Quantitative Extent of the Aerospace Industry in Mexico (2004-2020)

Year	*Companies*	*Jobs*	*FDI*	*Accrued FDI*
2004	65	10 500	470	4 300
2011	238	31 000	1 300	19 300
2015	350	38 000	3 200	27 500
2020	450	110 000	4 600	48 000

Source: Created by the authors based on data from FEMIA 2013

In Map 1 we can see that by 2013 a structure for relocation had been created and has been sustained until the present day (2017). The number of aerospace companies was 267, concentrated in five states (75.28% of the total), with four border states standing out and the rest spread across 13 different states of the Mexican republic. According to the information from the Ministry of Economy, by 2015 the number of companies had grown to 300 spread across 18 states, accounting for more than 43,000 jobs. The five states with the greatest number of companies are: Baja California (71), Sonora (52), Chihuahua (35), Querétaro (41) and Nuevo León (32) (Quintana and Ortigoza, 2015).

Map 1. Location and Distribution of the Aerospace Industry in Mexico (2013)



Source: Department of Heavy and High Technology Industries (MoE), Promexico, sourced from FEMIA (2013)

If one of the objectives of the aerospace industry is to arrange itself into groupings or clusters where the companies can divide the labor, feeding each other with regards to consumables, parts, components, assembly and the use of labor, the reality is that in some states, they only share a geographical space and are far from being a cluster or grouping in the strictest sense as they tend to be individual companies which work in an isolated manner. In this sense the Mexican Federation of Aerospace Industries (FEMIA, 2013) indicates that it is an industry with a high clustering potential. In Table 2 one can observe the different groups of the aerospace industry.

Table 2. Mexico: Main Groups within the Aerospace Industry (2013)

State	Speciality	# of Companies	Companies
Baja California: – Mexicali – Tecate – Tijuana	– Electrical and Electronic – Motor parts – Navigation and control instruments – Engineering and design – Electronic and electrical, manufacturing of parts	59	– Honeywell Aeroespace – UTC Aeroespace Systems – GKN Aeroespace
Sonora: – Hermosillo – Guaymas – Cd. Obregón	– High-precision machining of turbine components – Harnesses and cables	45	– Maquilas Tetakawi – Sonitronics – Qet Tech
Querétaro: – Querétaro	– Fuselage parts – Landing gear – Precision machining	33	– Bombardier – Grupo Safran – Aeronova
Chihuahua: – Cd. Juárez – Chihuahua	– Aerostructures – Fuselages – Precision machining for turbines	32	– Zodiac – Hawker – Honeywell
Nuevo León: – Apodaca – Monterrey – Santa Catarina	– Helicopter fuselages – Harnesses and rings from special materials	32	– Monterrey – Aeroespace – Frisa

Source: created by the authors based on data from the sources cited. The number of companies corresponds to map 1.

The companies found in Map 1 divide their activities into three areas of production as can be seen in Table 3: 79% dedicate themselves to manufacturing, or rather making and assembling components and parts for aircrafts; 11% to service and repair and 10% to research and design.

Table 3. The Aerospace Industry's Structure in Mexico (Companies' spheres of activity)

Manufacturing	*MRO*	*Engineering and Design*
Manufacturing and assembling of aircraft parts and components	Maintenance, Repairs, Operations	Engineering and Design
79%	11%	10%
– Cables and harnesses – Motor parts – Landing systems – plastic injection moulding – Fuselages – Repairs – Heat exchangers – Precision machining	– Turbines and motors – Fuselages – Electrical and electronic systems – Landing systems – Propellers – Dynamic components – Coatings: protective and anti-corrosive – Interior designs and installment – Auxiliary Power Units (APUs)	– Aerospace dynamics – Control systems – Flight simulators – Non-destructive testing techniques – Image and data processing – Equipment design – Embedded systems

Source: Ministry of Economy (2012).

This industry's production ability has led it to become the sixth largest provider for the aerospace industry in the United States with an estimated value of $7.5 billion dollars in 2017, a figure 18% higher than that in 2014, and generating 34 thousand jobs. The goal is to achieve the complete aircraft manufacturing cycle, from engineering and design, to making parts, maintenance, assembly and finally recycling (Garcia, 2017).

The activities in which each of these aerospace groupings is specialized is broken down into various stages of the supply chain. According to the National Strategic Aerospace Program (Secretaría de Economía, 2012, p. 9) "the Mexican aerospace industry is focused on basic activities across all segments, in other words, it is a Tier 1 and Tier 2 aircraft component provider".[5]

In a general assessment of the state of the aerospace industry in Mexico, certain elements such as the following stand out: in general terms it is a new industry which started operating in the 1990s. It is a highly complex industry due to the technological sphere which sustains it. It entails diverse production chains and demands professionals and technicians who are highly qualified in the subject and requires a level of collaboration between the public and private sector. The level of these requirements is a basic necessity despite being an industry with varying levels of local integration in the states where they find themselves (Casalet, 2013, 2014).

As we mentioned before, the aerospace industry, characterized by sustaining itself on high value added production processes which can in turn result in knowledge spillovers via its contact with local economies, is focused in Mexico on the different stages of manufacturing, maintenance, and repair. Nevertheless, the levels of co-location are different in each part of the country (Villareal ***et al.***, 2016, p. 170-172).[6]

The Aerospace Industry in Sonora

The current path of industry in the state of Sonora dates back to the 1960s. There are two major landmarks in its history: 1) the establishment of the Ford plant and complementary businesses in Hermosillo back in 1986 and 2) the offshoring of the aerospace industry in the 1990s. In both cases they found a climate defined by its proximity to the United States, the construction of industrial parks and buildings, the rise of outsourcing companies, favorable public policy and the training of human capital in institutions of higher learning.[7]

With regards to geographical distribution, if the activity of *maquiladoras* holds a special place in the economies of border towns and territories, the current dynamic is to relocate to coastal areas or in the mountain ranges of the state. The aerospace industry's relocation towards the center or the south of the state in particular stands out (Bocanegra and Vázquez, 2010, p. 137-143).

The growth is quantitative, as is the specialization of this industry in the construction of aerostructures, turbines and MRO (see Table 4). It is estimated that exports totaled 190 million dollars with the primary destination being the US (García, 2017).

Table 4. Aeronautics Industry in Sonora

Year	*Companies*	*Jobs*	*Strengths*
2009	38	5 000	Compound materials and turbines (simple machining)
2013	45	7 500	MRO, Aerostructures, turbines (precision machining, chemical and heat treatments)
2015	60	10 000	Aerostructures, turbines (forging, casting, coatings)

Source: Created by the authors based on information from Ministry of Economy from the State of Sonora (2016).

Nevertheless, in the context of a national industry which is concentrated in five states (Baja California, Sonora, Chihuahua, Querétaro and Nuevo León), previous studies show that despite the number of companies operating in Sonora, its technological profile is low and it is far from operating at the level of the industry 4.0 platform. It is also far from being part of co-location models found in clusters linked to the aerospace industry, or rather "there is no statistical evidence to think that the aerospace industry is geographically attracted to other industrial sectors in the region" (Villareal *et al.*, 2016, p. 192).

4. METHODOLOGY

Broaching this subject of study requires establishing quantitative reference points. It essentially requires the use of a qualitative methodology which allows one to look into the breaking down of the different productive areas and the value and supply chains in global productive processes.

In this case we followed a qualitative methodology of a structural nature, a methodology supported by the analysis of the selected contexts relevant to the topic of research. From these, individual cases were chosen, taking into consideration aspects like heterogeneity/homogeneity and accessibility. The selection was made through personal networks and contacts, i.e. individuals whose familiarity with the field and specific personal and social networks allowed for access to collectives which would have otherwise have been unreachable. The samples were not detailed beforehand but rather were configured on the go as the research process unfolded (Olas, 2016, p.26).[8]

The process of a methodological technique began with looking into the then current state of knowledge on the topic using a variety of sources such as books, articles, chapters in books, official documents and web sites. This search revealed that research into the aerospace industry in Sonora is still in the nascent stages[9] . Afterwards came fieldwork interviewing public functionaries from the government of the state of Sonora who are involved in promoting, attracting and helping establish the aerospace industry. From the interviews stemmed a need to carry out a trip around the state in order to gain a perspective borne of first hand contact with the industrial parks and companies dedicated to aerospace production. As part of this stage we made contact with managers at some of the companies, getting them to commit to future interviews.

The average number of aerospace companies in Sonora between 2000-2016 was 36, a number which grew to 45 in 2013 and 60 in 2015. Due to the shifts in the industry (companies moving in and out of the region), which obviously affect the numbers, the figure which homogenizes and represents stability for the sample is that found in the National Strategic Aerospace Plan: 36 companies. From this group the 12 companies most often mentioned and which make up 33.3 of the sustained average for that time period, were chosen for interviews.

Two semi-structured questionnaires with in-depth questions were prepared simultaneously. The first had 15 questions and was given to state functionaries from Sonora, covering three main topics: government policies designed to attract aerospace investments, the strengths and weaknesses which the government perceives in driving the industry forward and the challenges that it represents for the state. The second questionnaire, comprised of 30 questions split into four topics, was given to managers at the companies selected (or the representatives they chose for this purpose). The topics broached were: the company's primary profile (origin, type of production, consumables, and the destination of their products), productive processes (flexibility, innovation, their tier and insertion in their production chains and safety), workforce profile (jobs, education, hiring process, salaries, training) and challenges and vision of the aerospace industry's future (see Appendix 1 for the companies studied).[10]

5. RESULTS

The Government's Vision

If the origins of the aerospace industry can be traced back to the end of the 20th century, it is during the six-year period between 2009-2015 that its activity came to be at the center of the government's strategy. In the words of a functionary from the Economic Development Council of Sonora (Copreson):

> From the beginning of this administration, a program was made to see which industry would receive the most resources for its advancement, Sonora has other industries which are more developed like the mining and automotive industries. They saw a great opportunity in the aerospace industry, with investment plans and growth projections, which is why they decided to bet on it from the beginning (interview with Candelario Medina, 2014).

Along those lines, according to the same functionary, the most outstanding help from the government is that of training human resources: 16 students who had graduated from CONALEP were sent to Toulouse, France for training and now work for Latecoere Mexico making doors for Boeing's 787 Dreamliner; the Sonora Institute for Aerospace and Advanced Manufacturing (SIAAM) was founded to train candidates who could work in the industry; the state's higher education and technological institutions were encouraged to create a bachelor's degree in aerospace as can now be found in the Technological University of Guaymas. An interesting point is that the aerospace industry pays 1.5 times more than other industries and their personnel contracts are for periods between 20 and 25 years.

A direct question planted to the Copreson functionary on whether the aerospace industry can be considered an established and consolidated cluster elicited this response:

> The cluster…which is the most integrated is found in the Guaymas-Empalme region, the majority of the companies make components for airplane turbines (24 companies), there is a high level of integration in the supply chain between the established companies and there is a segment in common. In Sonora, there is no turbine assembly plant but, in the event there were one, it would go to Guaymas-Empalme; there isn't one right now because we are lacking two companies in the airplane turbine supply chain which prevent them from being made outside of their country of origin. They are only made in the US, Canada, and the UK. In Ciudad Obregon, there are three companies dedicated to MRO and one to design engineering (interview with Candelario Medina, 2014).

In the government's opinion, the primary competitive advantages are: the geographical location of Sonora and access to the primary groups of aircraft assembly plants and trained human resources as a result of the lessons learned from Ford-Hermosillo. Nevertheless, a weakness was pointed out in that they had yet to fully exploit the port of Guaymas, as well as

the access routes afforded by the highway system. Regarding the industry's challenges, they insist there are two main ones: improving human capital and the quality of the infrastructure in Sonora.

The Manager's Vision

Managers from various companies were interviewed in order to acquire information on the following topics: the business environment, the production process in relation to flexibility and innovation, the workforce's general profile and the challenges and future of the industry.

Business Environment

With the exception of the German company Robert Bosch, which established itself in Mexico in 1996, other companies established themselves between 2000 and 2011. The majority come from the United States and import consumables and export to this country as well as European countries. Their production is aimed at both commercial aviation as well as the military. Of the companies interviewed, ten make parts and one provides services via internet. A relevant factor is the versatility of these companies. Most have a mix of productive processes in that they manufacture for the aerospace industry as well as other industries. Another important fact is that with the exception of INCERTEC, which claims to be Tier 1 in the aerospace value chain, the rest are Tier 2.

Productive Processes

The majority of those interviewed agreed that the companies function via flexible processes and are constantly innovating. The company Horst Engineering de México, which produces steel and aluminum components for all types of airplane parts (part of the aileron, combustion system, fastening systems for levers or overhead compartments), dedicates

> […] 60% of its machinery to production and 40% to the development of original products. With Ametek aerospace, says the interviewee, … we started with two divisions two years ago, currently we have six divisions with them, distributed in the United States and production has increased 400% in two years, which is why we are acquiring more sophisticated higher precision machinery so that we don't have multiple operations but rather one machine which can do three operations as one. It costs more but it saves time and since volume is extremely high, it pays for itself in about three months (interview with Ramón Cota, 2014).

In another company, Minco Manufacturing, production is geared to precision machining, such as sleeves and retainers, the latter being parts used in fastening and adjusting fuel injection pumps while the former are used to join piping. "The flexibility of the productive process lies in that we change according to the client's needs", said the interviewee:

> We are running approximately 40 MPN for aerospace and 100 for the rest of the business, so yes, it's diversified. If the client requires high volume we can run at high volume, if they need low we do it that way. We work a lot with what is called SMED (Single-Minute Exchange of Die) where we try to reduce the time needed to prepare a machine or the production process as much as possible. Before the preparation process took 45 minutes, now it takes only 15. Likewise, we bet a lot on encouraging our personnel to find new things. For me, innovation is not having the latest craze when it comes to machines but rather innovating the processes (interview with Rafael Regalado, 2014).

The company INCERTEC (Innovative Certified Technical Plating), makes anti-corrosive coatings and bases its flexibility on the fact that "…it adapts to the clients' needs in regards to the processes and tools used and in that it meets a great variety of specifications." The company is in turn considered innovative "because it constantly…updates the chemicals and equipment for the process" (Interview with Jesús Cervantes, 2014).

The company Sargent Aerospace & Defense produces exclusively for the aerospace industry, specializing in their core business, rings and seals for fuel injection systems, piston rings and hydraulic pistons, and identifies its flexibility in the fact that "…it has the freedom to make changes and proposals for an already established process, although there are processes which are fixed." Regarding innovation, they said "we continuously improve our processes and the result is often the purchasing of better technology and equipment" (interview with Gilberto Hernández, 2014).

UTC Aerospace makes airplane turbine blades, which are high precision products, and their flexibility lies in that the company adapts to the needs of the client. Likewise: "the machinery that the company is acquiring is state of the art and we are constantly innovating by updating our production processes in order to avoid waste and be more competitive" (interview with Perla Navarro, 2014).

One of the few companies which is not based in the United States, but rather Germany, Robert Bosch, makes headphones and microphones for aviation pilots and claims that their flexibility lies in that "…we adapt to the needs of the client and produce for different sectors" (interview with Reyna Pérez, 2014).

Pinnacle Aerospace is a company which does not manufacture products but instead provides services. They carry out testing of "multi-area screens for aerospace devices" and their level of innovation has been acknowledged by Mexico's National Council of Science and Technology (CONACYT) on two technological innovation projects (interview with Alejandro Osorio, 2014).

In summary, the companies in the sample interviewed are highly flexible in their production process and are constantly innovating in a very Shumpeterian sense of the word: the aerospace industry is inserted in a production mentality where a company meets the conditions needed to fulfill the orders of industries with varied profiles; they supply different markets, make a variety of products (parts), introduce changes in the production process and are constantly innovating technologically. These specifications are those found in the theoretical framework of this piece, as developed by Coriat (1992).

Employment

According to data from 2013, the aerospace industry employed 9,430 people in the region, concentrated in Nogales, Hermosillo and Guaymas-Empalme, cities where one also finds the education centers (post-graduate, higher, technical) in which qualified staff for the industry are created.

The questions focusing on the workforce profile sought to answer questions regarding the level of schooling had by the workers in the company, the primary problems faced during the hiring process and the salaries. Likewise, they were asked if they outsourced their hiring process as well as their opinions and/or observations regarding the Sonoran manual labor and how it compares to other states.

The level of education of technicians and employees in the business can vary depending on the type of activity carried out. The majority of the companies have employees with a variety of levels of education and degrees: middle school, high school, technical, bachelor's, engineering and in some cases even master's degrees. In the particular cases of companies like Pinnacle Aerospace and QET Tech Aerospace, which do not make physical products, but rather dedicate themselves to testing multi-area screens and MRO, the level of schooling is strictly at the bachelor's level or higher.

The problems facing these companies at the time of hiring personnel varies according to their needs: one of the requirements is the use of English, a near-indispensable language for managerial positions in these companies, as their clients come from abroad, communicating with them and waiting on their requests requires mastery of the language.

A common assessment among these companies is that there is a lack of knowledge, experience and preparation. They even mention that what is taught at the educational institutions is far removed from the reality found in the aerospace industry's productive processes.

The employees of the companies come from a variety of institutions from around the state like private and public universities in addition to technical institutions, with some of the most noteworthy being: the University of Sonora (Unison), Monterrey Institute of Technology and Higher Education (ITESM) ,the Sonora Institute of Technology (ITSON), the Universidad Estatal de Sonora (Sonora State University), the Instituto Tecnológico de Hermosillo (Technological Institute of Hermosillo), the Instituto Tecnológico Superior de Cajeme (Higher Technological Institute of Cajeme), the Universidad del Desarrollo Profesional (University of Professional Development), the Universidad Tecnológica de Hermosillo (Technological University of Hermosillo), the Universidad del Valle de México (University of the Valley of Mexico), the Universidad Tecnológica del Sur de Sonora (Technological University of South Sonora), the TecMilenio University (UTM) and Mexico's National Technical Professional School (CONALEP). The engineering or technical specialties needed for the sector are mechatronics, industrial and electrical engineering on the engineering side, on the technical side it would be CNC machining or aerospace machining.

With regards to outsourcing the hiring process, the companies based in Guaymas and Empalme employ Maquilas Tetakawi, which assumes all responsibility for the workers, acting as a front or *shelter*. The companies doing the hiring based in the industrial park do not legally exist in the region nor in Mexico. Maquilas Tetakawi is responsible for finding personnel for all the companies when they are hiring and then sends profiles of the candidates which they consider fit their needs. Nevertheless, it is the companies which make the final call as to who they want and will hire via the *shelter*. Robert Bosch, Pinnacle Aerospace and QET Tech Aerospace hire their employees directly without the use of outsourcing services. In Hermosillo, American Precision Assemblers and Federal Electronics use Sonora S. Plan to hire their personnel and to manage their different *maquilas*.

The salary of employees varies depending on duties, schooling and position. The wages for operators is between 120 and 500 pesos per day while engineers make between 500 to 1500 pesos a day. It is interesting to note that some technicians make the same (or almost) as an engineer, depending on their experience and field.

In the case of specific production processes, like those found in Federal Electronics Hermosillo, 95% of the employees are women due to their manual dexterity which is essential for the processes and making the product in the factory. In other companies the gender make-up of the workforce is 50% male and 50% female. Notably, the majority of factory managers are men.

The majority of companies agree that Sonora has a highly qualified workforce for manufacturing. They also pointed out that for this industry to continue growing they need to develop the abilities, skills, knowledge and experience of the people interested in working in the field. Another point worth noting is that when they were asked how Sonora compared to other states, 100% of those interviewed stated they were unfamiliar with activities and/or specialties of other regions.

Prospects and Challenges in the Aerospace Industry

All the interviewed managers agreed that this industry has a great future ahead of it and on the challenges it faces. American Precision Assembler's opinion succinctly summarized the general consensus when they said:

> It has a promising future not only in this state but also at national level. Aerospace, aside from sounding particularly grandiose, covers many things. It includes technology, designing and developing parts, a workforce which is qualified such as technicians and engineers, operations and training. The wages to be had by people trained at those levels are high and they can aspire to even better wages if they have aerospace training. There are a lot less people qualified for this area, you learn a lot, it's a field with a mountain of knowledge due to all of its requirements. Furthermore, aerospace's core business is the commercial and military aviation industry; the part of the aerospace industry that is satellites, rockets and all that type of stuff is a large branch. The economic spillover which can be had with the establishment of this kind of company in the state is very important (interview with Liliana Molina and Roberto Darío Pérez Valencia, 2015).

What are the greatest challenges facing this industry at regional level?

> One thing which would facilitate the arrival of the aerospace industry, not only in Sonora but also the north of the country, is if the schools started to train their engineers in specialties which have to do with aerospace. They should have an area where they teach everything aerospace and that way they would be creating a qualified workforce to offer up to those companies. Another thing they need to do is make investments in the area attractive to these companies in the sense of simplifying the requirements for establishing factories and giving certain financial incentives so that the idea of coming here and establishing themselves is attractive; developing the infrastructure and making electricity cheaper so that the investment is more appealing (interview with Liliana Molina and Roberto Darío Pérez Valencia, 2015).

6. CONCLUSIONS

The current industry in Sonora is led by the electronic, automotive and aerospace industries which have varying levels of development. Even though their processes are on par with the general global economy, they are far from finding themselves at the front of creative destruction. Such is the case with the aerospace industry, whose production to operate and support the space and military industries, air transport and communications, finds itself at the level of manufacturing, maintenance and repair.

In Mexico, the aerospace industry is spread across 18 states of the Republic, but five groupings stand out with four of those corresponding to states bordering the US. One of those is Sonora, where the industry's establishments have changed in time and space, as their strategical location at the border, particularly in Nogales, faced challenges related to problems with the city's basic infrastructure and a lack of training in the workforce provided by the institutions of higher learning. This motivated the companies to move towards the center and south of the state (Hermosillo, Ciudad Obregón, the conurbation that is Guaymas-Empalme) where the right conditions exist for the industry to grow: available land, industrial parks, an environment of institutionalized support on the part of the government, logistics for transportation limited not only to land but with access to the port of Guaymas and the airports of Hermosillo and Ciudad Obregon, as well as proximity to the technical and higher learning institutions and primary research centers of the state.

This has allowed the creation of a mass of tacit and codified knowledge which has potentiated the possibility for expansion and greater complexity to move the companies to higher levels in the supply and value chains. Nevertheless, there exists a gap separating the technological deployment of the age of tele-robotics and telepresence and the knowledge and conditions to be able to insert themselves at the height of new knowledge to develop the industry 4.0 platform.

According to the main players in the industry, the managers interviewed, the companies currently operating have a high level of flexibility in their production processes in order to be able to attend the diverse requirements of the market and are facing the challenge of surpassing the limits of their knowledge in order to deploy the production process at its full potential. Nevertheless, the general opinion is that the human resources involved in the industry are lacking experience as well as a proper education in the skills that the industry demands.

An additional element is the integration of women in the production chains. In the company Federal Electronics in Hermosillo, 95% of the personnel are women while the majority of managers are men. This is an important factor for strengthening the industry for many are of the opinion that the competitive edge afforded by women in some segments of the production chain is superior to that of men.

A key point for the industry to be a factor in regional development is the level of integration and the generation of spillovers with local and regional supply and value chains, in order to leverage the competitive advantages to be had in Sonora. Until now, transnational companies have taken advantage of the comparative and competitive advantages that the state offers, while regional or national economic agents have lacked the strength to foster cooperation and the creation of networks needed to form to an industrial conglomerate.

Said weakness in the industry is also linked to the isolation in which it works: on the one hand, the technician or worker only knows his part of the production chain, ignorant of the structure in which they play a part. On the other hand, the worker is ignorant of the how's and why's of how more developed clusters in the country are developed.

APPENDIX 1: COMPANIES AND PEOPLE INTERVIEWED

Table A1. Information obtained from companies between 2012 and 2015

Name of Company	*Product Provided*	*Location*	*Contact*
American Precision Assemblers (APA)	Harnesses and cables.	Hermosillo	Roberto Darío Páez Valencia (ex production manager) and Liliana Molina (assistant)
Federal Electronics	Products for NASA: copper assemblies, harnesses, fiber optic interconnect assemblies.	Hermosillo	Rafael Esquer (plant manager)
Robert Bosch	Headphones and microphones for aviation pilots.	Hermosillo	Reyna Pérez (HR)
Consolidated Precision Products (CCP)	Turbine blades, seals, metal casting.	Guaymas	Dora Lunas Alejandres (plant manager)
G.S Precisión	Aerospace machining, CNC turning, CNC. milling	Guaymas	Marco Antonio Burgos Navarro (quality engineer)
Horst Engineering de México	Steel and aluminum components for airplane parts (part of the aileron, the combustion system, fastening systems for levers or overhead bins).	Guaymas	Ramón Cota (plant manager)
Innovative Certified Techinal Plating (INCERTEC)	Anti-corrosive coating services via chemical processes.	Guaymas	Jesús Cervantes (plant manager)
UTC. Aeroespace	Airplane turbine blades.	Guaymas	Perla Navarro (materials manager)
Sargent Aerospace and Defense	Plant dedicated 100% to aerospace products specializing in their core business, rings and seals for fuel injection systems, piston rings and hydraulic systems.	Guaymas	Gilberto Hernández (plant manager)
Minco Manufacturing	Precision machining such as sleeves and retainers, the latter are used in fastening and adjusting fuel injection pumps while the former are used for joining piping such as those supply water to the bathroom. All products are for interiors.	Empalme	Rafael Regalado
Pinnacle Aerospace	Testing (validation) multi-lateral displays for aerospace device displaying speed, pressure and/ or latitude.	Ciudad Obregón	Alejandro Osorio
QET Tech Aerospace	Aircraft maintenance.	Ciudad Obregón (Registro Fiscalizado Estratégico)	Anonymous
Copreson	New companies	Hermosillo	Candelario Molina (investments promoter)

Source: Created by the authors based on appendices by Becerra (2015).

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[2] For a greater understanding of a learning society, see Stiglitz and Greenwald (2015).

[3] A good example is the Mexican aerospace industry. The Company NC Tech in Querétaro, with the help of the aerocluster formed with the state’s government and the Aeronautical University in Querétaro (UNAQ), organized a conference in 2017 to present these advances during the Jornada de manufactura 4.0 (Manufacturing 4.0 Conference) (Pérez, 2017).

[4] TL note: this quote was translated directly from the Spanish version of this article.

[5] “The supply chain in the aerospace industry is primarily made up of original equipment manufacturers (OEM) and Tier 1, Tier 2 and Tier 3 suppliers.
OEMs take care of designing and developing new plane models, manufacturing the fuselage and assembling the plane, as well as the sale to the end client (e.g. Boeing and EADS). They are the most crucial part of the value chain and the segment is characterized by high barriers to entry due to the high associated costs and the technology requirements.
Tier 1 suppliers: are responsible for manufacturing systems and equipment essential to planes, such as motors, flight control systems, wings and fuel systems (e.g. Rolls Royce, GE Aviation and Pratt & Whitney). These generally have exclusive supply contracts with the OEMs.
Tier 2 suppliers: develop and manufacture parts according to the specifications given by OEMs and Tier 1 suppliers. They carry out subassemblies of systems and subsystems.
Tier 3 suppliers: they are responsible for supplying airplane parts and components to suppliers who are higher up the chain.
The supply chain gets support from the aftermarket industry (maintenance, repairs and major overhauls) which manages an airplane’s

maintenance and upgrades" (Morán and Mayo, 2013, p. 10).

[6] These authors did research to determine "business co-location patterns surrounding the aerospace industry with the aim of determining: 1) those productive sectors located in proximity to the aerospace industry, 2) the existence of a relocation pattern for different industries, as well as 3) the possible differences between these patterns according to the productive capabilities of the region and in relation to the aerospace industry with the goal of 4) specifying the current productive structures of the primary aerospace clusters in the country and contributing a resource that sets a foundation for analysis capable of proposing initiatives in the field of public policy" (Villareal *et al.*, 2016, p. 172).

[7] For a perspective on the industrial development in Sonora see Vázquez (2009) and Váquez and García de León (1992).

[8] For more on qualitative methodology see chapter 13 of *Metodología de la Investigación* by Hernández *et al.* (2010).

[9] For recent works see Becerra (2015); Becerra and Vázquez (2016); Ibarra *et al.* (2014) and Contreras and Bracamonte (2012).

[10] The "raw" content of the interviews can be seen in the appendix of Becerra (2015).

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