# REPORT ON
# INNOVATION AND KNOWLEDGE CREATION PROCESSES IN THE AERONAUTICAL CLUSTER IN THE REGION OF MADRID

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## 1. Introduction

During the last two years, the Spanish aeronautics industry has followed the same path of growth that has characterized it since the mid nineties, a time in which the industry underwent a restructuring and consolidation process, through mergers and the creation of new groups, for the purpose of relying on leading firms with the necessary capacity and potential to compete in an ever more competitive global market. The result has been a growth process that has allowed the sector reach a 0.43% of the Spanish GNP in 2003 and a 0.12% of the active population in Spain.

**Table 1 SECTOR'S KEY DATA 2003**

| | |
|---|---|
| **Employment** | **23,256 people** |
| **Invoicing** | **3,188 million €** |
| **Expense in R+D** | **13.9%of** |
| **Exports** | **69.8% of** |
| **Orders** | **199€ of invoicing** |

**Table2 IMPORTANCE OF THE SECTOR 2003**

| |
|---|
| **Represents a 0,43% of the Spanish GNP** |
| **Represents a 0,12% of the Spanish working population** |

Employment has increased progressively during recent years, reaching 23,256 jobs in 2003. Specifically, between 2002 and 2003, employment grew a 2.3%, creating 532 new jobs. As far as invoicing is concerned, the data is very similar. During recent years, the sector's invoicing has increased from 1,421 million Euros in 1997 to 3,188 million reached in 2003, which means a 55.5% growth rate.

Its present day entrepreneurial structure has a reduced number of large firms (>250 workers), a few medium size firms and a large number of small and very small firms. No more than 300 firms constitute the Spanish aerospace sector, of which 90% are small and medium size firms.

In Madrid the sector represents 61.4% of the national whole, and thus, it is the Spanish region with the largest volume of turnover. In absolute terms, this represents 2,400 million Euros. With respect to employment, the data is very similar. Madrid employs a 60% of the workers in this sector.

The aeronautics sector in the community of Madrid, as well as on the national level, has a vertical pyramid structure. At the top we find a very small number of firms known as final integrators or tractors, with a high volume of invoicing and high employment and with much potential and technological capacity. These are large firms that are placed at the beginning of the chain, given that they carry out the entire manufacturing or integration process of the plane. They generate knowledge and show important levels of investment in R+D. Among this group of tractor firms stand out EADS-CASA and Airbus-España.

Below these tractor firms is a second level of firms comprised by the so-called modular integrators or first class subcontractors. These firms are specialized in the production of new materials (composite), in design and manufacturing of structures, and in engineering services and design. These are leading firms in their respective business segments. They don't have the capacity to integrate planes, but do have the capacity for engineering of R+D on specific components, subsets, systems or equipment. They are highly specialized and have very competitive human resources. Their relations as subcontractors with the tractor firms is based on the idea of the "complete package". Within this second level we find firms like Hexcel Composite (components), CESA (systems and equipment), Gamesa Aeronáutica (design and manufacture of structures and engineering services) and SENER-Bóreas (aerospace engineering of production and design of structures).

The third level is composed of the second level subcontracting firms, specialized in one phase or more of the production process. They depend on the knowledge of the tractor firms and produce under their specifications. The smaller firms among this group usually work in mechanization and treatment of components and mechanical parts. Basically, more than 50% of the aeronautical firms in Madrid belong to this third group, among which stand out: Grupo TAM, Composystem S.A., ACATEL, G.A.Z.C., Talleres Dumadi, Mecanizados Escribano and many others.

The object of this report is to present, in an organized manner, the results of the qualitative analysis made by the team of the Universidad Autónoma de Madrid on the aeronautical and aerospace sector's cluster in Madrid.

The aim of the qualitative analysis is to learn how the creation and diffusion of technology in the aeronautical sector is produced from the information gathered through a convenience sample. Thus, the report is based on the information gathered through the semi-structured personal interviews held with the senior executives of fifteen firms within the sector, located in Madrid, and following the list of topics agreed upon at the meeting of Tor Vergata in November of 2004. The interviews took place between the months of November, 2004 and February, 2005 by the members of the team of the Universidad Autonoma de Madrid.

The firm sample largely represents the firms of the cluster. Five firms, with over five hundred workers were interviewed, including leading multinational firms in the sector (EADS, GAMESA, INDRA), another five with between fifty and five hundred workers and last of all another five with less than fifty workers. The selection criteria was above all, functional, given that each of these groups represents firms that play different roles in the process of creation and diffusion of technology. The group of large firms has a greater creative and dynamic capacity for the diffusion of innovation and knowledge through the productive fabric; the medium size firms have, in general terms, a certain capacity for incorporating innovations associated with the development of production engineering; and the small firms work according to the patterns already established by the firms under contract, though they also introduce know-how in "how to produce", thanks to the tacit knowledge they have acquired while working in the productive activity.

The report begins with a commentary on the specificity of the aeronautical activity which has a set of characteristics that, to a large extent, conditions the organization of production and the diffusion of innovation and knowledge. Following this is a description of the productive system of the aeronautical sector in Madrid which tries

to identify its dynamic in recent years to the extent of forming a cluster in which the interaction between firms and their physical proximity give them a certain functional consistency. Next, the question of the analysis of the mechanisms that facilitate the creation and diffusion of innovations and knowledge in the cluster and the role played by the milieu of the firms and organizations committed to the innovation process is put forth. The report ends with a consideration about the characteristics of the innovation process in the aeronautical cluster in Madrid.

## 2. The aeronautical activity

From the start, the main characteristic of the aeronautical and aerospace sectors has been the strong conditioning enforced upon it by the respective governments, given that the production of airplanes may be considered a public activity, and given its importance in national defence.

This trait has conditioned the sector, since, depending on the institutional tradition of the countries, the sector has either developed under the formula of the public firms, as has generally occurred in the case of European countries, or it has developed under strong regulations, as occurred in the Anglo Saxon world. This occurs both in civil aviation as well as in the military branch of aviation. Furthermore, the sector needed, precisely because it is strategic, large financial, industrial and technological resources. Thus, the aeronautical industry grows hand in hand with the public sector (defence), both in what concerns financial sources as well the necessary technological stimulus.
Yet, what is important today, is that we are seeing changes within the institutional framework of the aeronautical sector. Thus, it can be said that, though the public burden remains, the direction appears to be slowly distancing itself from its historical path. This change in institutional tendency began in the seventies, with the Airbus project, although the dynamic transition towards a new governance structure has not yet been accomplished.

What are the main characteristics that defined and define the aeronautical sector? There are five major characteristics that outline the sector from its consolidation since the first thirty years of the XX century. In the first place, this activity is very close to the defence of a country, and consequently, its production has the characteristics of a public good.

Secondly, European firms adopted the legal form of “public firm”, and thus a certain tolerance was established in the relations between productive public firms and the main client, or virtual monopsony, the State. Thirdly, the organization of production in the aeronautical sector has changed. Since the eighties, it has become a model that depends on network production and on the commercial and technological exchange between the firms of the cluster. In fourth place, the importance that science and technology have in the aviation industry, and last of all, the role played by the territories and local organizations and firms in the consolidation and restructuring processes of the aeronautical industry.

The aeronautical activity has traditionally been considered an activity that produced goods strategic for the defence of the country, and thus, public goods. The production of planes has generally been considered a strategic industry in all countries, as was the armament industry, which is why its financial impact in the budget of the State has traditionally been overlooked. Governments usually made reference to reasons of State in order to justify important investments and maintenance of the aeronautical activity. Although civil aviation, since the fifties, has developed enormously, and has steadily emancipated itself from the military industry, the government’s position continues to be important in aeronautical production. From financial support for the design and later development of the product, to the decision of who to sell to, and indirectly, how to sell the plane, the position of the government has determined the guide-lines in the history of aviation.

The aeronautical industry in Europe has historically been managed by the public firm, although there have also been private initiatives such as those of Dasault in France, Massersmitt in Germany and Fokker in Holland. This contrasts with the U.S. where practically all are private firms.

When the firm belonged to the public sector, the government’s control was indeed strong, which caused the sector’s isolation from the market. This conditioned and determined its costs structure, and thus its price. Keep in mind that the proto-typical client of the firms was usually the very same government, which is why the few public suppliers of each country would usually coincide with the few demands, also public, of the same country. The result was a close relation between firms, ministries with

technical management, and government clientele. This has led, generally, to the fact that aeronautical production had high costs and low financial returns, which is why improved profitability would only be achieved with privatizations, restructuring and deregulation, or all at the same time. Organization of production has changed significantly since its beginnings, when the industry was basically artisan, and where creativity was labour intensive given the level of know-how at the time and given the difficulty of mechanizing production. In fact, the industry still keeps some of those characteristic traits and thus, along with the high level of applied knowledge in the productive processes, it continues to use skilled labor- intensive processes.

The aeronautical industry is a good example of the transformation of organization of production. Since the sixties the Fordist model in which the manufacturing phases of production was made “in house” was abandoned, and aeronautical production became an activity where the final product is made thanks to the collaboration between a wide network of inter-related firms, between the matrix and the suppliers, and through collaboration contracts that include all aspects of plane manufacturing. In fact, one of the key aspects of modern productive organization of the aeronautical industry is the existing relationships between firms. Furthermore, the growing internationalization of production, as occurs in the case of Airbus, and the integrated feature of the production process gives the product an international character.

Lastly, the expansion of the aeronautical activity is due to the development of scientific knowledge and its application to the productive activity. The production of planes is nurtured by basic and applied science that is already known, and its main contribution is due to innovation based on the design, the industrial development and the learning process that the productive process incites. In other words, the industry places itself at the center of what should be a society that accepts and creates technological change: great innovative applications are created and adapted in the manufacturing of a new product and in its productive processes.

Innovation represents the most dynamic profile of the aviation industry where the total innovative effect is a multiplier of the individual innovations of the participating firms as a whole. In turn, these firms, if they wish to participate in the manufacturing program, must have the strictest quality controls in their processes and products. This is

why, when talking about levels of technology, we mean the technological capabilities of the firms in any project. In other words, the technological level of the firm cluster.

## 3. The aeronautical cluster in Madrid: organization and firms

Since the early nineties of the XX century the aeronautical cluster of Madrid, as we know it today, begins to take shape as a result of the effects of restructuring in the aeronautical industry at the international level, and because of the restructuring and international integration of the major firm of the Spanish aeronautical sector, CASA (Construcciones Aeronáuticas, S.A.) created in Madrid in 1923.

Among the effects of the restructuring of the aeronautics sector should be pointed out the development of civil aviation, whose rapid change surpasses that of the military activity, and is the result of a greater world demand and the concentration of firms. The growing concentration of this industry will inevitably lead to a world-wide oligopoly in the area of brands and types of civilian planes with two big producers of wide range civilian aircrafts and standard wide fuselage (Boeing and the EADS consortium).

Simultaneous to the expansion of the aeronautical production and this concentration of manufacturers and brands takes place, we see a process of internationalization of aeronautical production that affects the productive system of every country, and specifically the manufacturers of systems and components, as well as the auxiliary industry, as is the case of Spain. The European consortium EADS is present in Spain, and particularly in the region of Madrid through the EADS-CASA and Airbus-España corporations, as a result of the CASA integration process within the multinational firm.

CASA is the catalyst of this process, since December of 1999, it stops being a public firm and incorporates itself in the EADS complex. Before this, since 1972 it was part of "Airbus Industrie", as a founding member, and enjoyed a strong take-off in the productive activity, which had influenced the dynamic and transformation of the Spanish and Madrid aeronautical industry. The change in its organization of production model conditioned the reorganization and size of the aeronautical cluster of Madrid.

The aeronautical cluster of Madrid is formed by a geographical concentration of very different firms, inter-related and specialized in the production of specific parts of the

products that the two large oligopolies of the aeronautical industry commercialise, particularly EADS, as well as auxiliary firms, and firms and organizations that supply services to the cluster.

At the center of the aeronautical cluster of Madrid is the EADS consortium, through two of its firms EADS-CASA and Airbus España. CASA, since its attachment to EADS in 1999 has had to adapt itself to the organization in divisions of EADS, giving way to EADS-CASA, where activities related to military transport planes and products derived from Airbus are found. In other words, it is the Military Transport Planes Division of EADS. Its activities related to the Airbus program have passed to the corresponding division of Airbus of EADS, Airbus-España, S.L., entirely controlled by Airbus Industrie SAS, with headquarters in Toulouse (France), who is responsible for the design, development and manufacture of structural components for all models of Airbus planes. Its activities focus on the initial specialization, with a clear competitive advantage over other production units of Airbus in Europe, of the horizontal stabilizers for Airbus´s family planes and and the manufacturing of composite materials (epoxy carbon fibre, Kevlar).

Around this central nucleus exists a set of firms that are related to the EADS group, but who also work with Boeing and other firms and organizations of other aeronautical, aerospace and industrial activities, as is the case of INDRA, Gamesa, Sener and Tecnobit, that have been studied in the sample[1]. INDRA, with 6,400 workers is the best and most international Spanish firms in the informatics and electronic equipment for defence (avionics and defence platforms) market. For the aeronautical industry it manufactures products simulation and automatic systems for maintenance. Gamesa Aeronáutica, with 1,774 workers, forms part of a group, who originally manufactured weapons, and today manufactures and supplies products, installations and advanced services in the aeronautics and renewable energies sector. Their main products are wings, fuselage and pylon for engines and interiors. Tecnobit, with 300 workers, has specialized in the market of defence electronics and information technology, and devotes a 78% of its sales to the aerospace sector (particularly military, with a 63%) and its exports represent more than 66% of its sales. The last is Sener, a group of firms with

[1] Appendix I: List of the 15 firms analyzed

950 workers, devoted to engineering, aerospace industry and the environment. The division working in the aeronautical and aerospace field produces, among other things, the mechanisms and structures for air navigation, orientation systems, launching systems for rockets and satellites, airport systems and engines.

In the aeronautical cluster of Madrid there exists another group of firms specialized in the manufacture of goods and services for the aeronautical industry, among which the following have been studied: CESA, GAZC and AERLYPER. CESA is a subsidiary company of CASA, with 217 workers, specialized in the development of new systems and equipment for the new models of airplanes, specifically for Airbus family. Its present volume of sales is distributed between the civil aeronautical activity, 52% and a 48% in the military. For the airbus program it carries out specific tasks such as the supply of landing ramps, of deposits and hydro-mechanical accessories. GAZC (Grupo Aeronautico Zona Centro), in turn, is a group of firms created in 1999, with around 100 workers that supply services within the aeronautical sector (single piece mechanisms, final assembly of sets of pieces, quality control) and its main customer is EADS-CASA. AERLYPER is a family firm with 50 workers, that began its activities in agricultural aviation in 1961 and four years later turned towards the commercialization of small planes and complete maintenance of engines, propellers, electrical accessories, radios and flight instruments. Today it is devoted to the design and integration of planes and **optronics s**ystems; it manufactures those parts of the aircraft that facilitate the installation of communications equipment, screening systems or the electronic war of self-defence.

A relatively important part of the firms in this sector manufacture products and supply services for other industrial activities, and some of them even come from industries that have undergone a strong restructuring process as occurs with TAM, APRIM and RAMEN, who previously produced for the automobile sector. TAM (Técnicas Aeronáuticas Madrid) is a group with around 400 workers, which began in 1991; but that since its start in the sixties produced spare parts for the auxiliary automobile industry until its crisis in the eighties. APRIM is a family firm, with 46 workers that began in the sixties to work for the auto-mechanical and transport sectors, and that today has diversified its clientele which includes automobile industry**,** electronics, medical equipment, aeronautics and defence. RAMEN is a small family firm with 13

workers, created in the late fifties and that has evolved in its specialization and manufacturing process. Originally, it was devoted to the manufacture of machinery tools for the automobile industry; its entry into the aeronautical sector took place in the early seventies, when some of the auxiliary firms of the auto-mechanical sector began maintenance work for planes for companies like Iberia. Thus, a new specialty began for the firm, that allowed it establish relations with CASA, and that continues today, basically for the Eurofighter 2000.

Finally, a group of firms exist that shape the auxiliary sector of the aeronautical industry, among which we find Industria Carmona and Quality Metal. Industria Carmona, a family firm with 17 workers is a boiler maker's, metal and mechanical workshop, which works for Airbus, supplying large scale supports for the moulds in the manufacture of airplane parts. Last of all, Quality Metal, an affiliate of the TAM group, with 17 qualified workers, was created in the nineties and devotes over 80% of its production to the aeronautical activity (25% to civil aviation, and 55% to military) and manufactures airplane parts for the Airbus program.

The aeronautical cluster of Madrid, still underway, it appears to display an organization that obeys the Hub-and-Spoke system of firms, given that around the large firms of the EADS group the cluster firms organize themselves to supply goods and services that allow construct airplane parts designed by EADS-CASA and Airbus. Furthermore, it is an example of a productive system of goods that incorporate modern knowledge and whose strength lies in the fact that the firms create and share this knowledge between them. Yet the cluster of Madrid also forms part of a network of centres and clusters located in different territories of Europe, influenced by the decisions of EADS.

The firms that manufacture the products and offer services in Madrid are widely varied, as we have just seen. In some cases the firms have a long tradition in the production of highly technical goods and services, present in national and international markets of aeronautical products; in others, they are new firms that have surged as a result of existing opportunities within the aeronautical market, in some cases promoted by already existing firms (spin off) and in other cases as a result of the creation of new ventures. Yet, industrial firms also exist, who have a long manufacturing tradition, that

at present they devote to the aeronautical activity by incorporating the knowledge acquired throughout the history of their firm.

## 4. Networking within the aeronautical cluster

The relations between the firms and the actors of the network are a central mechanism in the functioning of the aeronautical cluster of Madrid, since they establish the economic, technological and power flows that direct the cluster's dynamic.

The relations between the aeronautical firms in Madrid vary greatly. In some cases the relations are formal and explicit, and obey the decisions of the firms and actors and seek clear objectives, as occurs with commercial exchange of goods and services, the commercial relations between suppliers and clients and the technical relations between firms. Yet, informal relations based on personal contacts between firms and actors are also important. This often means relations among engineers, ex-employees and personnel that have worked in the sector many years. In this sense the significance of relations between engineers and executives that work in firms within the sector and others that work in public administrations and organisms should be pointed out, given that the characteristic of the aeronautical activity during decades was linked to the public sector and have created strong ties that affect the economic and even technological relations, and this facilitates exchange within the network.

One of the keys to the functioning of the aeronautical productive system in Madrid is undoubtedly the commercial relations established between the firms of the cluster, as well as with the suppliers and clients from other clusters and activities with whom local firms relate.

Change in the organization model of aeronautical production has promoted important changes in the aeronautical firms by externalizing a part of the production phases and developing subcontracting to different levels. It is common practice that, for example, between the final manufacturer of the A 380, and the firm that produces and supplies the parts there exist two or three firms in the contractual chain. An increase in commercial transactions between suppliers and clients, and a change in competition between the

firms of the cluster was produced because of the externalization of certain functions and subcontracting at different levels within the firms. These mechanisms have made the production system more efficient and flexible, despite certain drawbacks, especially for the auxiliary firms that carry out the least complicated tasks.

EADS-CASA is a good example of the changes in the organization of production, given that it continues with the design, production, termination and assembly functions but, in recent decades has transformed itself and has adopted new forms of subcontracting and externalization. Today, part of the design and tasks previous to the production, production itself, and assembly are functions under subcontracting. It is estimated that around 28% of production is externalized or subcontracted. Parallel to the increase in subcontracting, EADS-CASA works even more as a subcontractor, supplying aero-structures, wings, tails and tanks. A 40% of its production is manufactured for other firms- half as a risk partner in Airbus-, including international aeronautical manufacturers like Boeing, that request the design and manufacture of components for its planes from them.

But, what does given and received subcontracting mean, exactly? It is very difficult to establish a priori the general rules of collaboration between one firm and another, particularly in the case where the definition of the contract is made jointly between the supplier and the buyer. Indra, for example participates with the client in the process of defining the product or service to be developed in order to meet its needs. The specifications of the product or service is determined between the supplier and the buyer, and once this point is reached, Indra will take charge of the design, development and manufacture of the product, and for this it will need to subcontract some part of the process or of the product to one of the firms that shape its subcontracting network.

Subcontracting can be carried out in different ways and its content will depend on the type of product or service under contract. Thus, the TAM group specifies the forms most commonly used:

- Realization of complete packages: from the conceptual design to the final product certified and delivered.
- Establishment of mixed teams (firm-client) in charge of accomplishing complete packages

- Mobility of human resources to the client premises for engineering, trials, assembly, metrology and manufacture.
- Logistic support for the product, from the design phase to the results of the material.
- Partial subcontracting of design activities, manufacture, assembly or verification of mechanical components.

Subcontracting is widespread among firms in the sector, but it is gradual according to size and significance of the firm and according to the value of the final product. Gamesa, for example, gives around 60% of its production to other firms located in the Basque country, Madrid, Andalusia and also in southern France. CESA, on the other hand, subcontracted other firms, between 2002 and 2003, a total of 7 million Euros, which represents approximately a 50% of its production. This type of relation is usually established with firms located within the local (such as the municipality, metropolitan area and region of Madrid) and national area, though there are also examples of firms working on the EU (4%) and international (1%) level. Ramen, a small firm, subcontracts about a 30% of its production to firms within their municipality and the Madrid metropolitan area. Aprim subcontracts a 20% of its production to firms within their area, particularly in the autonomous community of Madrid. Other firms like Tecnobit do very little subcontracting. The client firm usually indicates the characteristics that the products requested should have, and often point out the processes that should be used and supply the raw materials. Sometimes support is given to production engineering and quality control, and even transfer of technology. The firm selects and chooses its suppliers carefully, so that they will be capable of meeting the technical and commercial requirements that the first level buyers demand. For the purpose of maintaining quality and control of production, the suppliers must give proof of their capacity through both general and specific certifications. Both parts carry out the quality control of the product.

The relations among subcontractors and suppliers are characterized by strong competition between them for obtaining contracts to participate in the manufacture of specific products. Thus, competition between firms that manufacture final products has shifted to the subcontracted firms that supply parts of the product. Nevertheless, cooperation among competing firms is not uncommon, particularly when there is much

work or one of the subcontracted firms needs the help of another member of the network to get the job done.

An important characteristic is the internationalization of the production activity in the aeronautical cluster of Madrid. The bottom line is that the production of aircrafts (civil and military) has become international, both in its manufacture and in transfer of technology. EADS is an international consortium that manufactures its products, components and structures in different territories, where their network of suppliers is located and its sales policy and clients have an international profile. The construction program for the A 380 foresees the assignation of work to the network of local suppliers of the EADS firm, but suppliers from other countries like Japan, Korea, Malaysia and Australia are also on the list.

At the same time, the suppliers and subcontractors of EADS are connected to other international networks. Indra, for example, operates in over 40 countries of the five continents, and of its annual income, approximately one third comes from international markets. Their main clients are in Europe and the U.S. and they own subsidiary firms in the U.S., China, Portugal, and Brazil. Among the clients of Industrias Carmona are the Spanish subsidiary of American, German, and Norwegian firms and as suppliers, again foreign firms. For example: the metal plate they use comes from Indonesia and Bulgaria and the machinery is manufactured in Europe. TAM, on the other hand, is under contract to Airbus GMBH (Germany), Eurocomposites AG (Luxemburg), Bröjte (Germany), Fisher FCC (Austria), and Fokker Stork (Holland). Tecnobit has important international clients like Kaiser Electronics and Lockheed Martin from the U.S., Bae Systems from the U.K., EADS from Spain and RAFAEL from Israel.

An issue that concerns the functioning of the Madrid cluster has to do with the power relations within the network. Contrary to what it would appear, given the oligopolystic characteristics of the aircraft market, even though the pressure of the large oligopolies is felt, the entrepreneurial fabric tends to develop product diversification and market strategies, for the purpose of limiting its influence. No doubt there are firms that work mostly for a strong client, as is the case of GAZC that works mainly for EADS-CASA, manufacturing parts, metal structures and aeronautical tools and even distributes products and services and manages its subcontractors network in the central area of

Spain. But, firms like AERLYPER exist who have a widely diversified portfolio and do not subcontract. Among their clients we find all of the official organisms for plane and helicopter operators, including the Armed Forces; all of the operators and private fleets of planes and helicopters, the centres for aeronautical maintenance and the flight clubs. They have a portfolio with over 2000 clients, and among their suppliers are the multinational firms who manufacture equipment; above all, American and European companies like Bendix King Avionics (Honeywell), Garmin International, UPSS Aviation, Rockwell Collins, Sandel, BF Goodrich, Becker, US Gauge and the French group Martec (Serpe-Iesm).

Large firms that work for the large oligopolies of civil and military aviation also maintain a widely diversified portfolio. In the case of Indra, most of their clients are institutions that go from the Navigation Authority of Norway or Uruguay to the European Spatial Agency, and the Spanish Ministry of Defence or Sogecable. In this same trend we find Sener, among whose clients for aeronautical products we find the Spanish Ministry of Defence, the European Spatial Agency, Arianespace, Boeing, Saab-Ericcson, Canadian Space Agency, and Alcatel.

The diversification of production and markets is a strategy adopted by both large firms and small. Tecnobit, with 300 workers, has a widely diversified portfolio of clients and products: planning system, management, control and evaluation of flight operations for the Spanish Air Navigation Agency (AENA); services for the writing and elaboration of technical aeronautical documents for AENA, Telefonica (telephone company) and Spanish railway (RENFE); terminals for maritime patrol planes for the Spanish Air Force; improvement and maintenance of management systems for Caja Madrid. The main clients of Quality Metal, a firm with 17 workers, within the aeronautical sector are CASA, and the production of specific mechanical tools and precision tables for vacuums for the factory division of planes; Gamesa Aeronautica, for whom they have designed, developed and manufactured tools, and Industria de Turbo Propulsores (ITP) for whom they have made motor parts for the Eurofighter. Furthermore, in other sectors like transportation they work for national clients like the train companies TALGO and RENFE and in the nuclear sector the have clients like TECNATOM.

In any case, in the aeronautical cluster of Madrid the relations between firms and actors has a strong asymmetric character, in the sense that when EADS is the final client, that condition the exchange among firms, its power within the market is transformed in a functioning mechanism of the local firm network, who manufacture the components and the product.

The formation of the network and the consolidation of relations is based on agreements, contracts, alliance between firms in the network that allow firms obtain scale economies in the production and in the research and development of products and processes, and on the other hand, reduce production costs. This kind of relations also affects the subcontracting firms who allow the territorial takeoff of the large aeronautical firms. In this sense, the attraction of the Madrid region has much to do with the availability of skilled human resources, the existence of firms and organizations that accumulate knowledge and know-how, as well as the existence of a manufacturing productive fabric that has taken shape during decades.

Finally, among the existing relations between firms, the technical relations based on the exchange of coded information on products, processes, materials and organization of the sector acquire a strategic value in aeronautical activities. Access to technical information, interactive learning between different firms within the network and the diffusion of innovations and knowledge generate a set of ties between the firms in the aeronautical sector of Madrid that strengthens and gives cohesion the network of actors. On the other hand, it should be remembered that in technical exchange between firms they lean on contacts and personal and professional ties.

## 5. Innovation within the aeronautical cluster

The aeronautical and aerospace activities have internalized important technological innovations, in their products, processes and organizational models in recent decades. The new forms of organization of production have conditioned the innovation process, as shown by the case studies. These activities differ from other high technology activities by the lack of importance of the radical innovations applied to the products and processes, and it is surprising to note the importance of the incremental innovations throughout the different stages of the production process. No doubt the spectacular

results known today would not come about without both the upgrading in human resources and the necessary financial support.

The aeronautical industry is a high technology activity clearly evident in the final products that appear in the market, but also in the firms business models and in the constant search for product quality. When EADS has an idea for a new commercial plane, or a new military plane, or helicopter, or any of their products, the Center for Research and Development of the consortium is in charge of designing the basic characteristics of the prototype. Once it is approved and tested, it is built, and the production of the different parts of the plane is assigned to the productive units pertaining to the consortium that have the most competitive advantages for producing each component. Next they contract and subcontract specialized firms for carrying out each and every task, component and structure. Given the kind of organization in aeronautical production, once the prototype is made, a continuous improvement process begins in its manufacturing, since the firms and engineers that work "in a network" (Concurring Engineering) have the possibility of introducing improvements. Thus, the new product is the object of continuous and increasing improvements.

On the other hand, the complexity of aeronautical and aerospace products offers the firms the possibility of adopting business models based on technological innovation, as occurs with INDRA, who has won a leadership position within the Spanish information technology market and defence systems. This is thanks to the creation of certain products with built-in solutions, adequate to solving problems posed by the clients. In this way, the aeronautical and aerospace engineering firms offer the client solutions from the first step of the conceptual design to the production of goods and services, that is, in goods and services that affect's the entire value chain of production. SENER, for example, has developed the following innovations:

- The design and development of the electronic control unit that unfolded and singled out APME satellite antennas, and permits the duplication of the transmission capacity of the Hispasat system.
- Participation in a European project for reducing noise in aeronautical motors.
- Design, development and production of the aviation engine EJ-200 for the Eurofighter/Typhoon.

- Design, development and supply of landing equipment for the X-38/CRV, a crew rescue and return vehicle in the International Spatial Station.
- Development of cybernetics in real time for managing the different calculus processes in the control center for the new European system EGNOS/GNSS-1 of satellite navigation.

The aeronautical and aerospace activity maintains its essential activity of high technology not only by the continuous introduction of knowledge but by the continuous quality control in the manufacturing of products, components and structures. The firms apply quality controls recognized within the sector by authorities and clients, which improves the firm's competitive position and they also have the certification as official purveyor (seal of approval) given by the major clients. In the case of Tecnobit, for example, this seal of approval has been given by its major clients: Kaiser Electronics and Lockheed Martin in the U.S., Bae Systems in the U.K., EADS-CASA and Izar of Spain, and Rafael of Israel. These certifications are a recognition that the firm has the necessary knowledge and skill, as well as the necessary equipment, for producing the product or service in question. This serves as an "international accreditation" that allows it compete within the market. The large firms like EADS-CASA, Airbus, or even the Spanish Ministry of Defence requires the suppliers/purveyors, and subcontractors of services, components and structures the necessary certifications in order to work and produce them.

The type of organization in aeronautical and aerospace production conditions both the firm's and the firm cluster's innovation process, as can be seen when analyzing the amount of knowledge required in the production of a plane. EADS feeds on internal knowledge produced by their own highly qualified human resources, and this places them at the front of world technology, and external knowledge, also first rate, which comes from a rather small number of firms normally independent of firm headquarters. These "tractor" firms have special relations with the EADS, that include taking risks in the manufacturing of their respective products, and the strategies of knowledge that they share. Besides these horizontal flows of knowledge described, EADS projects vertical flows of knowledge towards firms situated on lower technological levels. There are gradients in the respective levels of knowledge and one can see how the tractor firms with a relatively high level of knowledge are able to subcontract to a third party part of their production, and also those auxiliary and support firms that have specialized in

simpler, less innovative tasks and whose capacity for independence from EADS or tractor firm is very limited.

These small, often family-run firms, are the most numerous. They normally work with the blueprints given by the EADS or the tractor firm and their activity has a low level of added knowledge. In recent years, some of them have passed from being mere receptors of the subcontract based on blueprints to participating in the design of the parts that the firms that commission the subcontract wish to produce. It is a qualitative change and an example to be followed by the rest of the small and medium size firms within the sector since it establishes the pattern of quality to be followed.

But it is the organization model of each firm that conditions the internal process of innovations, and CESA is a good example. Once the executive committee accepts the proposal from the technical and commercial areas for the manufacturing of a new product, the area of new products development or the R+D center develop the knowledge for a new product. Once the product is developed and assessed, information and knowledge pass to the operations area, where knowledge relating to processes and development of new techniques (process innovations) is produced. Next, it goes to the departments of manufacturing and sales.

In this way, the aeronautical and aerospace firms of the Madrid district, both large and small, create and develop product and process innovations. More examples can be found, within the reports of TAM, SENER, APRIM and GAMESA. Furthermore, the innovations affect the use of new materials and even market innovations, as the Gamesa report points out.

The innovations created and introduced in the aeronautical and aerospace cluster firms of Madrid are mostly incremental. In the case where the aeronautical firm faces the challenge of creating a new airplane and the manufacturers require new specifications, is when a big push to innovation process and introduction of knowledge in products, processes and materials of the sector is produced. This often means adaptations and development of already existing knowledge. The adoption of innovations associated with new information and communication technologies is transformed into changes in management and in the organization of the firms.

The adoption and adaptation of technology from other activities comes about naturally in the aeronautical and aerospace industry because the productive system in aeronautics is an open cluster in which the firms are linked to other clusters and productive systems. As mentioned before, some of the firms in the cluster originated in other manufacturing activities, such as the automobile sector, others work today for different sectors some akin. Within the aeronautical and aerospace sector the firms pass from certain productions to others with ease. Lastly, the adaptation of existing technologies in other sectors is made in an almost handcrafted manner since the aeronautical and aerospace sectors are highly mechanized and the activity is very specific and not very standardized, besides strict following of the rules and regulations that characterize the productive activity.

The technological improvements that are incremental in nature are due to the transmission of formal and tacit knowledge. It is not only a question of transmitting the information that is in the blueprints and designs, in the specification of the products or in technical documents; the question is the knowledge that is the result of a person's and a firm's learning that allows for an interpretation of the formal knowledge, and above all, that permits apply the knowledge accumulated by the firms and individuals. Thus, in small firms like Industrias Carmona, without the capacity to create their own formal or scientific knowledge a flow of tacit knowledge within the firm and with the rest of the firms in the sector is produced. The same occurs with GAZC that has accumulated knowledge and know-how over the years that allows them produce parts according to the client's needs. This acquired capacity gives the firm a competitive advantage with respect to other firms in the sector.

Last of all, firms in the aeronautical and aerospace cluster can only respond to the challenges that producing high technology goods can mean and have the capacity to innovate if they have the necessary skilled human resources and make the necessary investments in Research and Development (R+D). In innovative firms like INDRA human resources are their main qualitative advantage. The capacity to innovate and add value to the supply can only come from a highly qualified team. According to Indra "it is the people that research, learn, teach and ultimately, create the products and process innovations. For all these reasons, the management of human resources is one of the

target areas for Indra. Their objective is to create an atmosphere, a culture that emphasises quality and innovation, establishing a management model for the human resources that assures flexibility, capability and personal professional development of all the workers. Thus, during 2003, the training activities have increased significantly, both in class hours as well as in total investment. Training itineraries are also used as a tool for planning individualized training and give priority to training activities. In sum, one of the pillars on which the philosophy of the aeronautical and aerospace firms of the cluster of Madrid lies is to encourage the culture of innovation.

Thus, upgrading the workers skills is one of the actions upheld by the more dynamic firms. Nevertheless, in the less innovative firms the "human resource" factor is also strategic because it allows them accumulate a stock of tacit knowledge, produced as a result of the work done for the more innovative firms of the cluster. The availability of skilled and trained workers with higher education is ever more important in this process, but the technicians and qualified workers that have learned on-the-job and working in a diversity of different jobs and departments within the firm is also important (see the Ramen report). In some of the auxiliary firms like Industrias Carmona they face the problem that some of the specialists and trained workers, such as boilermaker, are hard to find. This means that this kind of profession, so necessary in order to finish the parts as required, tend to disappear. Because of this, vocational training for specialized jobs such as welder, boilermaker, driller and lathe operator, are important in order to fulfil the jobs in the activities of the sector.

Finally, the more dynamic and innovative firms require units specialized in the creation and adaptation of technologies and knowledge in order to make product and process innovations. Technology in aeronautics and aerospace activities for the conception and development of products is crucial, and the more dynamic firms pay more attention to research, product development and innovation (R+D+i). Yet, the firms that fulfil less complicated tasks within the aeronautical firm network are also aware of the importance that investment in innovation has for them.

There are differences in the amount of financial resources devoted to R+D+i. The more innovative and dynamic firms make an important investment, innovation and development effort: Indra devotes a 7% of the total budget to this objective; Sener a

12% of their turnover; whereas Tecnobit devoted to investment in R+D+i almost four million Euros in 2003, which represents a 21% of their turnover and close to 18% of total expenses. The smaller less dynamic firms, who base their competitive strategy on acquired knowledge and experience over time and who keep it a secret, also devote part of their resources in innovation, as do Aerlyper and Aprim, who devote a 2% of total costs to investments in R+D.

## 6. The process of innovation: learning and entrepreneurial strategies

The aeronautical activity means high technology, whose innovation process is based on scientific advancement. The cluster firms share in a constant search for new applications in order to transform the product and adapt it to the changes in the demand, and in order to produce more efficiently. The innovation processes in the aeronautical cluster of Madrid are essentially systemic, as shown by the refuelling in-flight mechanism for planes. EADS created the concept and the product, and the execution of the work was given to CESA, after a public tender, and they in turn subcontracted its execution to a set of small firms, among which RAMEN took part. The innovation process is produced thanks to the participation of all the firms of the network, each according to its abilities in the aeronautical industry's value chain. In short, the innovation process is the result of the technological strategies of the firms that compete in each of the segments of the value chain of the aeronautical production filiere.

As mentioned before, all the firms of the value chain participate in the innovation effort. The management of innovation for all parts and components of products as complex as those of the airplanes the aerospace industry would be very difficult and expensive for a single firm. The new organization of aeronautical production opens up a solution since it allows the firms of the cluster, specialized in such complex tasks, to work jointly and introduce innovations in all phases of production, and ultimately, form and innovation network.

Each firm specializes in a certain type of task that leads to the production of the final product and exchanges within the network of the aeronautical productive system the goods and services it produces or requires. The introduction of knowledge from each firm within the cluster to another stimulates the appropriation of tacit knowledge

embedded within the firms, reduces innovation development costs and time of production and application of new techniques and technologies, and also stimulates the diffusion of knowledge within the network of firms as a result of commercial transactions, the circulation of ideas and concepts.

The central element in the innovation process is the sharing, within the network, of the accumulated knowledge in each of the firms of the cluster as a result of the learning process in the production of each of the component parts.

As Arrow pointed out, learning in the production process may explain the increase in productivity in industry and this effect is much more important when the form of organization of production is flexible and integrates a wide number of firms and workers, as is the case of the aeronautical and aerospace cluster. The flow of accumulated tacit knowledge in the network impregnates all of the productive fabric and each one of the firms.

Thus, innovation is a learning process that comes about as a result of the productive and entrepreneurial capabilities. In the case of the aeronautical industry innovations are produced and disseminated because learning is interactive. We see then that even though the original design and the characteristics and quality elements of production of an airplane depend on the specifications of the main firm headquarters, it is no less true that the technical participation of the engineering firms and of the suppliers, particularly of the large groups, is ever more crucial. Most of the development engineering of the main components of a plane (beyond initial ideas and blue prints) is carried out thanks to the collaboration between the engineers of the main firm headquarters and the engineers of the main suppliers.

The existence of commercial, professional and technical relations within the aeronautical cluster facilitates the diffusion of knowledge between the more innovative firms and the less dynamic firms. As mentioned, the firms in charge of simpler tasks receive the necessary specification about the parts from the client. Yet, when a continuous relation exists between clients and suppliers, the supplier often produces the parts without added information, and thus, both information and transaction/negotiation costs are reduced. In this way, a proactive action takes place at all levels of the network

between the effects of the two types of learning: one is the result of the productive experience embedded within the firms and workers, and the other the result of the interaction between firms and workers.

Transfer of knowledge between one firm and another in the aeronautical productive system means an exchange of knowledge and know-how that transforms the aeronautical cluster into an innovative cluster. The transfer of technology is done through the mobility of the specialized personnel of the firms, consultancy services supplied by the engineering firms, but also by the large innovative firms, as well as through the circulation of R+D results from one firm to another, based on the technology contracts signed by suppliers and clients. In this innovation diffusion process a key role is played by the negotiation process itself between clients and suppliers given that both in the definition of the contracts as well as in its implementation, the accumulated knowledge of the firms is transmitted. Because of this, it can be said that subcontracting represents an exchange of knowledge and know-how between one firm and another

However, given that that the firms in the aeronautical cluster of Madrid are located in an environment where economic, social and institutional agents and actors exist, the learning process of the firms within the aeronautical sector acquires a collective dimension. Learning becomes collective precisely through the relations that the firms that are investing have with the actors of this environment.

The view held by the aeronautical firms of Madrid on this point varies widely. INDRA, for example, indicates an easy going relationship with the universities of the region and with other public research organizations with which it participates in different R+D programs, such as the PROFIT Program and the European Union framework program of R+D+i. SENER points out that they undergo R+D projects with the Polytechnic University of Madrid. CESA, in turn, collaborates with research centres like INTA and the CSIC (Consejo Superior de Investigaciones Cientificas), with the School of Aeronautical Engineering of the Polytechnic University of Madrid, and the Chemistry Faculty of the Complutense University of Madrid. In this way, they have access to the results of basic research and can undergo applied research independently, which is also facilitated by its participation in the PROFIT program and the Entrepreneurial

Innovation Plan of the Madrid Institute of Economic Development (IMADE). Gamesa recognizes its cooperation with public and semi-public industries for the development of products and processes.

Yet, the firms that have a smaller projection, like Aerlyper and Industrias Carmona, point out that they have little relation with public research centres and universities (as well as with the public administrations), due no doubt to the fact that they participate in the innovation process through the application of knowledge accumulated by their experience in the production of components through incremental innovations. The question is not one of size, however, but rather by the work done by the firm in the production of planes and aerospace products. Ramen, for example, with thirteen workers, has a strong network of relations for cooperation in the development of product innovation with institutions like the CSIC, with the departments of Physics (Condensed Materials) and Applied Chemistry of the Universidad Autonoma de Madrid, with the Institute of Microelectronics of the Universidad Autonoma de Barcelona and participates in national programs like PROFIT and regional programs like PIE (see report on RAMEN).

In this way the firms of the aeronautical cluster of Madrid coordinate themselves in order to innovate through commercial and technical exchange that facilitates the existence of an articulated and flexible production system. Yet, the firms of the cluster act with very different innovation strategies, according to their specialization and function in the firm network.

The firms at the center of the aeronautical cluster, linked to EADS, introduce product, process and organization innovations for the purpose of improving competition, improve quality and strengthen its positioning in the final products market. Their international R+D+I centres think up new products, design the general paths of production and the specifications that guarantee product quality; their management areas define the organizational strategies and location of activities, as well as the logistics and assembly of the final product. Thus, they stimulate the innovations in each phase of the productive process. Through internationalization of production and trade they open up the market, reduce production costs, and above all, have access to other innovation and knowledge networks. Through the mechanisms of contracting and

subcontracting they try to extract from the productive system all of the knowledge accumulated and provoke the surge of new knowledge within the network. Lastly, the leading firms have stimulated cooperation with other firms both of the group and of the cluster for the purpose of developing new products and new processes, which has favoured transfer of technology within the network.

The leading innovative firms, capable of developing new products and processes, attempt to satisfy the needs and demands of their clients, improve product quality and reduce production costs with its innovative strategy. Their creativity is developed in the laboratory, when seeking solutions to the problems posed by the production of new goods and services. Furthermore, they develop new ideas and products with other national and international firms, either through ad hoc agreements and contracts or by participating in European R+D projects; often this is done with firms they have worked with before and who share the same values (see reports on CESA and GAMESA). They also carry out a strong human resources policy, through personnel training, as well as emphasizing the culture of innovation. They have assumed that the internationalization of their activities facilitates cost reduction in production and optimal use of the knowledge developed in other areas. On the other hand, these firms depend on the network of subcontracting firms, who permit them carry out the contracts. Finally, the development of new products is the result of the application of knowledge that derives from other activities and sectors, in whose productions they take part or with whose firms they have commercial and technological relations in order to diversify their activity.

Last of all, low intensity innovative firms, whose creative capacity is focused on the introduction of small changes and improvements as a reaction to the pressure to innovate posed by the competition in the markets, they attempt reduce production costs, satisfy the clients demands and keep the market quota within the subcontracting network. Because of this, they value the tacit knowledge acquired, and this allows them introduce incremental innovations, particularly in what concerns production processes. Also, its adaptation to the client's needs and demands forces them conclude their commitments in a short period of time, and they often finance their operations since the clients cannot always face payment as diligently as required.

Thus, knowledge emerges throughout the network and affects all phases of the productive system that is necessary for manufacturing an airplane or aerospace product, but the firms do not always take the necessary actions in order to protect their work through formal mechanisms like patents. Innovative firms in general, have a propensity to patent their innovations, as is the case of Airbus España who has developed 13 patents in the last five years, or the case of GAMESA, that have achieved 12 patents. Nevertheless, one can observe little pressure to register patents, as mentioned in the case of CESA, who has not patented its innovations in recent years, as for example with the refuelling in flight mechanism made for EADS. The explanation for this is related to the fact that once a component is made for final assembly of aircraft, the firm that carries this job out has the "right" to manufacture it during the lifetime of the model it was designed for, and the firms keeps the industrial secret.

The majority of small and medium size firms, that make incremental innovations do not usually register patents as occurs in Industrias Carmona or Tecnobit, in some cases due to the very dynamic of subcontracting that impedes making changes in the products, and in other cases, because they consider that by keeping the industrial property it is not necessary to patent innovations. Nevertheless, some of the small firms think patents convenient, as does RAMEN, a firm with 13 workers. Thanks to its participation within the Entrepreneurial Innovation Program of the Region of Madrid its R+D activity has increased, as well as its wish to take risks, and so, its wish to introduce and patent its new products in the international market.

## APPENDIX I

1. AIRBUS España
2. EADS
3. INDRA
4. SENER
5. CT Ingenieros
6. GAMESA
7. CESA
8. RAMEM
9. Grupo TAM
10. TECNOBIT
11. G.A.Z.C.
12. APRIM
13. AERLYPER
14. Quality Metal
15. Industrias Carmora