From A300 to A350: technical and organisational innovation trajectory of Airbus

Med Kechidi

NACELLES
Passée et Présent de l'Aeronautique et de l'Espace
N° 6 Printemps 2019

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Med KECHIDI
Framespa (UMR 5136)

Med.kechidi@univ-tlse2.fr

Abstract **:** The aim of this paper is to show that Airbus's success can be attributed to two types of factors. First, each new aircraft model has produced a technological breakthrough in the design and manufacturing of aircraft. Secondly, Airbus's capacity to evolve their industrial organisation model in keeping with technological transformations. In this trajectory, modularization and outsourcing policies have played major roles. In particular they play a major role in the emergence of new actors the pivot-firms. These firms have a critical position in management of technical and organizational interfaces between the architect-integrator and the firms participating in the design and production of aircrafts.

Key words**:** Airbus, industrial organization, innovation, modularization, outsourcing, pivot-firm.

1 Introduction

The factors which explain the Airbus's commercial success are various and diverse. Some of authors attributes Airbus's competitive advantage to the quality of organization and management of the supply chain. For Rose-Andersson et al. (2009), the evolution of the different forms of organisation in aeronautical supply chain is an efficient response to the evolution of markets and competitors. Similarly, Nolan and Zhang (2002) argue that modern aircraft have become so complex that the competitive advantage resides in the capacity of aircraft manufacturers to coordinate the supply chain and to integrate the various components of the aircraft. According to Cagliano et al. (2004) or Ehret and Cooke (2010), it is in fact the rationalization of the production process as a whole that accounts for Airbus's performance. For other authors (Rose-Andersson et al. 2009), an evolutionary approach shows that it is the Risk-Sharing Partnerships that are at the origin of the creativity and innovation involved in the aircraft production process. Acha, Stefano and Prencipe (2007) support that learning and forms of dissemination of knowledge are essential in the success of aeronautical

[1] A first version of this paper was published in International Journal of Technology and Globalisation (2013, Vol.7, N°1/2)

programs. In order to underline Airbus's success market, Campos (2001) highlights the family strategy through A320 and A330 ranges, while M. Givon and Rietveld (2009) show the comparative advantage of having a fleet of modular aircraft.
The point in common between all these explanations of Airbus's competitive advantage is the leading role they attribute to the dynamics of innovation in a complex product industry. Their other similarity is that they mostly look at what is occurring « outside » the firm, and they do not relate technical innovation to organisational innovation.

In this paper we will take a look at the technical and organizational dynamics that are behind Airbus' industrial strategies. The adopted point of view is : the embracing of a status of architect-integrator of aeronautics systems (and not as an aeronautics manufacturer), the increase in the modular decomposition of the airplane building process, the emergence of pivot-firms as well as the innovations – in particular those related to the composite materials, the integrated modular avionics and the embedded systems – make a profound reorganization of industrial model of the European aircraft manufacturer. The purpose of the article is not to propose an explanatory model with all the factors.

The aim of this paper is to focus one two types of factors. First, each new aircraft model has produced a technological breakthrough in the design and manufacturing of aircraft. Secondly, Airbus's capacity to evolve their industrial organisation model in keeping with the technological transformations. Without indulging in excessive technological determinism, it can be said that the successive adoption of technologies has generated profound modifications in the industrial organisation of the aircraft manufacturer. They have also completely reconfigured the relationships between the different participants in the aircraft manufacturing process. More precisely, the positive relationship between technological choices and organisational forms is concretely observable through Airbus's programmes. Airbus's technological expansion can be construed as, for each new programme, a break with the old technological paradigm as well as the adoption of a new organisation of production. According to us, it is this technological and organisational dynamic that contributes substantially to the commercial success of Airbus.

Two factors seem to us to be crucial in this organisational model and its evolution: firstly, high modularisation and its corollary, high integration of aeronautical systems, and secondly, the politics of refocusing and outsourcing. These characteristics are admittedly shared by other manufacturers, but, according to us, they are in more pronounced in Airbus's case. Today, the reinforcement of these mutations announces the emergence of a new industrial organisational model: "aircraft manufacturers" are progressively becoming "architect-integrators" of aeronautical systems (Cagli et al. 2009). It is this historical, technical and organisational trajectory which we will analyse.

The main idea underlying this analysis is that there are positive correlations between technology (and innovation) and the organisational forms that produce complex products. More generally, our basic hypothesis is that technological changes require organisational set-ups that are compatible with the nature of these changes. Therefore, we feel it is relevant to approach these issues from the point of view of the industrial model and inter-firm relations (Zuliani, 2016).

There will be three stages to our analysis. First, we will present the spatial distribution model of Airbus's activities between the different actors (countries) that participate in aircraft manufacturing. We will note that, from its origin, the organisational model is widely spatially distributed between different production sites and different players. We will also see that the division of labour between the different partners (German, French, and British) has changed very little over time. Then, we will analyse the technological trajectory of the different programmes. We will see that the technological breakthroughs successively introduced by each new aircraft have consequences on the organisational model of the firm. Finally, we will look at the modularisation and the integration of systems. We will see that a reinforcement of these two characteristics of aircraft manufacturing leads to a pronounced redistribution of the roles of the firms involved in the aircraft manufacturing process. This redistribution manifests itself by the emergence and development of pivot firms.

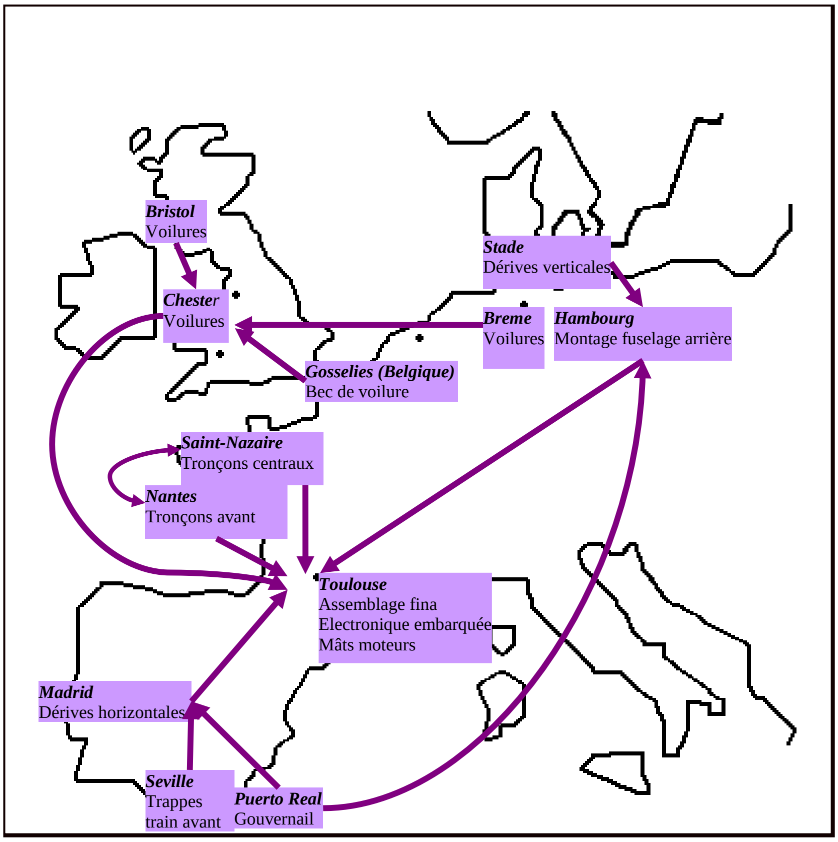
2 Airbus's European spatial organisation activities.

Several theoretical and empirical frameworks account for the clustering and anchoring factors in aeronautics (Agrawel and Cockburn 2003; Cooke and Ehret 2009; Niosi and Zhegu 2010; Kechidi and Talbot 2010). In the case of Airbus, the industrial organization is based on a division of labour at national, European and international levels founded on the main abilities of each production site (Kechidi 1996; Talbot 2000). The specialization of the sites has not been significantly modified since creation of the consortium in 1970. The production cycle of an Airbus is done within the boundaries of a quadruple division of labour:

- A European division of labour between the four national companies that are involved in EADS, United Kingdom, Spain, Germany and France. There are in Europe 16 sites of production which participate directly at division of work.
- A national distribution of labour orchestrated by the national company. In the case of Airbus France, production is divided among four production sites (Toulouse, Nantes, Méaulte, Saint-Nazaire).
- A dispatching of tasks among the different plants within the same site. For instance, for the Toulouse site, tasks are divided among the four plants of the site (Blagnac, Colomiers, Saint-Martin du Touch and Saint-Eloi).
- A division of labour between Airbus and a vast network of subcontracting firms located in France and abroad.

For distribution of workload on a European level, the most common organization is to build the wings in the United Kingdom, the tail units in Spain, the fuselage in Germany and the cockpit and the central section of the fuselage in France. The final assembly is done either in Toulouse or in Hamburg. The specialization per site didn't change since the beginning of Airbus project.

Figure 1 Logistics of an Airplane assembled in Toulouse



Nevertheless, that specialization is not perfectly transverse to all the programs. Indeed, depending on the model of the plane, the division of labour may vary. Thus, the wings of the A300, A310, A330 and A340 that are made in Broughton are first routed to Bremen in order to add equipment before being redirected to Toulouse where they are assembled, while the wings of the A380 do not transit through Germany. The A320s are assembled in Toulouse while the other planes of that family (the A318, A319 and A321) are assembled in Hamburg. This duplication of the assembly sites reflects the regular resurgence of the confrontations between the European industrial partners, the German partner wanting to take care of the very symbolic act of doing the final assembly of some Airbus aircraft, for national prestige reasons but also because the teams based in Hamburg master the technical and organizational skills needed for such tasks.

Like a giant puzzle that needs to be put together, the assembly of an Airbus generates numerous inter-sites flows. Even if they introduce a more functional organization and a stronger horizontal integration, the current reorganizations do not fundamentally question the current distribution of industrial tasks, at least on a mid-term basis. The expected configuration over the next few years is most probably the end of the industrial duplications with a specialization of the Toulouse and Hamburg assembly sites depending on the planes: in Toulouse the long haul aircraft and jumbo jets (A330-340, A380 and A350) and in Hamburg the A320 and its future successor.

However, the impact is very noticeable when it comes to the nature, the density and the content of the relationships between Airbus and the firms that participate directly or indirectly to the construction of the aircraft. That impact seems to generate the industrial and organizational conditions necessary to create a new organizational model of aeronautical activities. Before underlying its main characteristics, let's take a look at the evolution of the main programs, since it seems to us that the trajectory of innovation and of the industrial model is linked with the technical and organizational trajectories. These trajectories illustrate the industrial evolution of Airbus and the affirmation of market logic. This market logic replaced, during the 80s, an arsenal logic in which public intervention was very strong (Muller 1989). While an aircraft used to be considered successful it is was technically impressive, a good aircraft is now an aircraft that sells. From a symbolic standpoint, we have gone from a technical success but a commercial failure (Concorde) to a commercial and technical success (Airbus).

3 The innovation paradigm: "all up front", "all electric", "all composite"

In order to understand what is happening nowadays in this sector, it is necessary to take into account the background of technological innovations that have marked the evolution of the Airbus programs. At every stage, these innovations have constituted a paradigm break in the sense that they introduced innovations and new product architectures. Without indulging in excessive technological determinism, it can be said that the successive adoption of technologies has generated profound modifications in the industrial organisation of the aircraft manufacturer but also in its relationships with the subcontracting firms. If the increase in complexity in aeronautics is nowadays mainly observed in avionics and embedded systems, it can also be found in the whole design and production of the aircraft from the beginning of the first programs.

The A300 was the first long-range twin-engine jet with a large fuselage. It also unveiled the "all up front" control cabin. This innovation enabled two-man aircraft handling and introduced a new approach in the design of the product. The A300 started the "a good aircraft is an aircraft that sells" era. In terms of the outsourcing process, during this phase Airbus manufactured most of the aircraft components internally. It was a classical subcontracting situation where firms functioned as external workshops supplying components according to the detailed design provided by the manufacturer.

In 1984, the introduction on the A320 of fly-by-wire control as well as a new cockpit design generated an authentic revolution in that area. Electrical control and auto flight unveiled the era of the mass arrival of electronics and embedded systems. In this case as well, this had an effect on Airbus's industrial organization. The whole architecture of the airplane was partially revisited. The mastery of electrical systems became a fundamental specific asset.

In 1987, the A318/A319/A320/A321 and A330/A340 families introduced a quasi-standardization of the cockpit equipment. Aircraft belonging to the same family came to have the same instrument panel, the same attitude control procedures, the same avionics and almost the same systems. These similar configurations allowed the same crew to fly all the aircraft belonging to one family. Maintenance and operating costs were also reduced.

The technological breakthroughs made with the A380 were notably innovations linked with the size of the airplane and Integrated Modular Avionics (IMA). The size and the weight of the airplane have required the development of electric and hydraulic sub-systems for transporting energy that do not generate large weights nor important head pressure losses. The A380 sped up the era of the "all electronic airplane". This concept replaced the hydraulic central systems that are linked though complex circuits by electro-hydraulic systems that are dedicated to each piece of equipment. This innovation enabled important weight gains and a reduction of the production and maintenance costs.

The other innovation introduced in the A380 was the integrated modular avionics. Until the A380 program, the avionics systems were made of a range of linked numerical devices (calculators), each dedicated to only one function. Because this meant a multiplication of devices, it generated massive loads and costs. The IMA adopted by the A380 (and by the B 777 and 787) meant abandoning that principle of a dedicated resource in order to use one architecture for different applications. This electronic organization favoured a large upgradability of the software functionalities since it allowed for elements to be changed without needing to change the computer science architecture of the aircraft.

If there was a major change with the introduction of more electric technologies in aircraft, "the integration of systems and the standardization of avionics could represent a much bigger change, which would allow a better management of the fleets within the companies and a better valuation of them" [2].

The benefits of this kind of technology are clear. These are typically technologies that improve the performances of the aircraft while reducing the manufacturing and maintenance costs as well as the weight of the planes. From an industrial standpoint, going from the "one calculator for each function" logic to a "one calculator for various functions" logic reduces the number of stakeholders in the manufacturing of the electronic modules and allows the delegation of the coordination function to a sole actor, a pivot-firm, that will have to organize the subcontracting tasks.

Although the A350 adopts technologies that have already been tested on previous programs, among others the A380 and the A400M, it pushed further the "all electric" and "all composite" concepts. The percentage of composite materials thus went up to 52% compared to 38% on the aborted version of the A350, while the amount of aluminium and lithium stayed at 20%. This evolution toward composite materials was another vehicle of the mutations that affected the aircraft manufacturer and their partners. The presence of composite materials in the Airbus programs has not ceased to increase since the A300. Thus, while the level of composite equipment was of 5% on the A300-600, it reached 25% on the A380.

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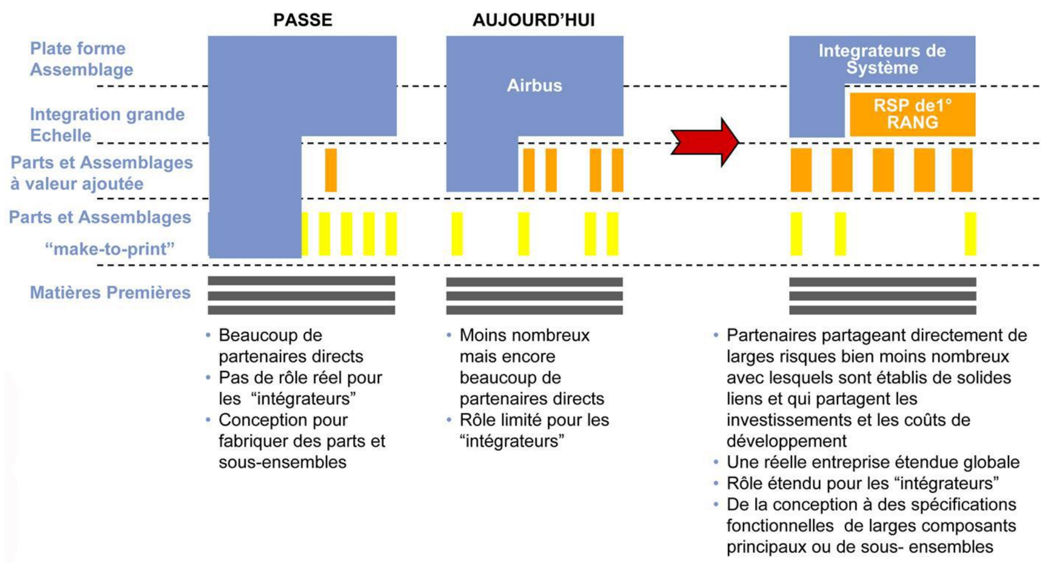
[2] Emmanuel Grave, vice-president of the aeronautics division of Thales, Air & Cosmos, November 24th 2006.

This brief “technical history” of the successive Airbus programs clearly shows that the deployment of each new aircraft model was accompanied with important technical innovations. This seems to illustrate Lawrence and Thornton’s (2005) point that the success of an aircraft depends crucially on its novel characteristics in comparison with competitor’s models.

Clearly, the “New Airbus” announced by Power 8 Plan in 2007 and Power 8+ Plan in 2008 aims to refocus the activities on the core competencies of the firm and reconfigure all relations with supply chain partnerships .

Figure 2 : The new supply chain partnerships organisation



Source : Airbus

These competencies are at the heart of the profession of aircraft manufacturer and include the design of the global architecture of the aircraft and the cabin, the integration of systems, the assembly of components and the customisation and testing of equipment. Other activities, that involved technology that is completely mastered or common, are outsourced. By strengthening its status as an architect-assembler, Airbus positions itself upward and downstream of the value chain. All the activities that are considered strategic from the technological, industrial and market standpoints are undertaken internally. This trend translates into an important increase in outsourcing non-strategic activities. This outsourcing is thus based on the creation around the firm of a stable network of partners with complementary activities in which lasting relationships are contracted and partnership links are created with the objective of improving performance while sharing risk.

The observed trend, particularly in the last few years, shows an increasing focus on Airbus's core business and an emphasis on outsourcing policy[3]. More than this, it demonstrates a real transformation in the status of aircraft manufacturers. Airbus and Boeing and other aircraft manufacturers radically changed their way of building and developing new aircraft (Amesse et al. 2001; Destefani 2004; Kechidi 2006; Cagli et al. 2009). In the past, aircraft manufacturers designed, conceived and built their planes mainly internally. Nowadays, they increasingly defer the design and production of whole sections to partners. Therefore, they go from being an "aeronautics manufacturer" to being an "architect-integrator of aeronautics systems". In the context of this evolution, the modularization of aeronautical systems has played a central role.

4 Modularity: technical, organisational and cognitive dimensions

The literature on modularity is based on H. Simon's theories on the decomposability of complex systems (1962). This conception of modularity, called modularity of the product or technical modularity (Ulrich 1995; Cohendet et al. 2005) is firstly a tool aimed at reducing complexity. "Modular architecture proves to greatly reduce the complexity of the complex systems by proposing a decomposition into autonomous subsystems, as it is possible to develop and pre-assemble them separately, linked on to another by relatively stable interfaces" (Frigant 2005, p.5).

Without limiting it to this aspect, product decomposability is a strategy to reduce the production complexity and rationalization. A modular object is then a complex product composed of subassemblies, produced independently of one another but that can be linked together to form a coherent system, stabilized by standard interfaces.

Through decomposability, the modularization of complex products enables to reduce the complexity of technical objects. It also enables to rationalize the organization of production processes and the hierarchical structure, as recalled by H. Simon through his parable about watchmakers named Tempus and Hora· were two watchmakers renowned for the quality of the watches they would design. They had such a good reputation that they were often interrupted during their work by clients who wanted to place an order. The more famous they were becoming, the more calls they would receive in their respective work-shop. However, Hora's activity prospered while Tempus went bankrupt. The explanation of these two fates is the following: each watch designed by both matchmakers involved 1000 components. Hora designed his watches in a way that "he would combine ten elementary components into small subassemblies, and then he would combine ten subassemblies into larger subassemblies, and these in turn could be combined to make a complete watch" (Simon 1962, p. 470). By contrast, Tempus did not decompose into stable and homogenous subassemblies. Every time the phone would ring, he would abandon his current assembly which would immediately fall apart. After each interruption, Tempus would start again the entire design process. Considering a reasonable interruption probability

[3] For example, Boeing subcontracts more than 70% of the equipment of B787. Airbus considers a similar approach for A350 by subcontracting 50% of the tasks linked with the aero structure to external firms.

for both men, H. Simon shows that in the end, it takes 4000 time more time to Tempus than Hora to finish assembling a watch (Simon 1962, p. 470).

The perspective developed by Sanchez and Mahoney (1996) is rather different; it is indeed not focused on the product. They developed the idea according to which there are positive correlations between the evolution of complex products development processes and the organizational forms that create them. The modularity-product perspective is coupled with an organizational perspective in which “modularity is presented like a specific structure in terms of coordination and labour division that particularly aims at minimizing transaction costs” (Cohendet et al. 2005, p. 122).

With the works of Langlois (2002), Baldwin and Clark (2000) and Brusoni et al. (2001), both perspectives of technical and organizational modularity are completed by a strong cognitive dimension. This dimension means that the knowledge underlying the products (design, production, and assembly) falls within the modules’ combination and assembly. In other words, modularization is also a modularization of bodies of knowledge that give rise to the products.

In fact, Brusoni and Prencipe (2001, p.184) questioned this product-organization-knowledge trilogy when they recalled that the literature on modularity was based on three basic premises: “(i) there exists a positive correlation between product, organizational and knowledge modularity ; (ii) modular product architectures enable increasing specialization, both within and across companies ; and (iii) modular product architectures allow for coordination to be achieved with minimum managerial effort”.

From this point of view, modularity represents the end of integrated firms and the emergence of particular organizational forms; which come within the theories of inter-organizational links, such as the “producers networks” (Langlois and Robertson, 1992), “modular networks of production” (Sturgeon, 2002), “loosely coupled networks” (Brusoni and Prencipe, 2001). Also, modularity becomes a management strategy for the supply chain and the inter-firms relationships.

5 Modularity and system integration: the emergence of pivot-firms

Modularization is not a new phenomenon in the aeronautics industry (Araujo and al. 1999; Amesse and al. 2001; Acha and al. 2007). Recent changes announce a deepening of this type of organization as well as a strong redistribution of the roles of the firms involved in the aircraft production process.

A modular structure involves a product architecture decomposable into modules connected to each other by more or less standardized interfaces (Baldwin et Clark 2000). The architect firm designs the general architecture of the product and manages the interfaces between the different modules during the integration of these modules (Ulrich 1995; Bresnahan and Greenstein 1999; Frigant 2005). The architect-integrator therefore occupies a strategic position all along the value chain, but mostly intervenes in the upstream and downstream stages.

Furthermore, a modular product architecture facilitates incremental innovation, either by adding functionalities to product components, or by transforming one of these components. A modular product can therefore regularly respond to modifications in demand (R. Langlois and P. Robertson (1992)). Similarly, it speeds up the development of variations on a same design. This is typically illustrated by the A320, 321,319 and 318 families of aircraft.

Modularization is based on the technical and cognitive division of the production processes (Ulrich 1995; Baldwin and Clarck 2000). From then on, the processes that generate the products are such that the organization of the firms active in those processes must be rethought (Langlois 2003; Frigant 2005). In a modular organization, the architect delegates the design and the production of modules and components of the end product to specialized firms (Ulrich 1995; Sanchez and Mahoney 1996; Brusoni and Principe 2001; Ulrich and Eppinger 2008). Its role as a supervisor is to control the manufacturing of sub-units and to ensure the compatibility of the interfaces between modules.

The increasingly modular organization at Airbus mainly involves delegating to specialized firms – pivot-firms or *"Hub firms"* (Jarillo 1988) – increasingly important components, for instance the whole aero structure, embedded systems, the landing gear. The bigger the size of the units and sub-units, the lesser the coordination duty of the architect, as the number of interfaces to control decreases along with the number of modules that need to be assembled. The economic advantage of modularization is also clear in terms of the cost decrease through the reduction in the number of direct partners. The pivot-firm can then play the role of architect firm for the units that it is in charge of. It articulates the technical and organizational competencies of the other participants (Kechidi 2008, Cagli et al. 2009, Gilly and al. 2011).

Technical dimension it's a modular decomposition. Complexity indicates inter-relationship, interaction and inter-connectivity of elements within a system and between a system and its environment (Mitleton-Kelly 2003). A complex system can be described as "one made up of a large number of parts that interact in a non simple way" (Simon 1962, p.195). In such system, the performance of the whole is threatened even if a single part does not function properly. Consequently, designing complex systems turns out to be complicated. As a solution, Simon (1962) suggests reducing the number of distinct elements by dividing the whole system into subsystems which in turn are broken down into smaller components and so on. If this decomposition assures one-to-one mapping between components and functions, it enables components decoupling and interface standardization, and thus is considered as "modular" (Ulrich 1995).

Even though the complex products are more and more modularized, which should allow, by definition, a decoupled organization to develop these products ; we witness on the contrary more and more collaborative relationships between the system integrators and the suppliers (Howard & Squire 2007). This seemingly contradictory situation can be explained by the fact that firms pursue different strategies in regards to modularizing their products on the one hand, and outsourcing parts of these products on the other hand. More precisely, while a firm can decide to modularize its product by pursuing marketing, production, financial or technological strategies, only the two latter can lead to outsourcing practices. In this regard, modularization of complex products is primarily driven by concerns about production efficiency whereas the reason why modules are outsourced is rather related to financial and/or technological concerns.

In case of complex product development process, problems have to be resolved in a top-down principle (Ulrich & Eppinger 2003). The system-level design phase during which the complex product is decomposed into subsystems and these into many components becomes critical. The architecture of the entire product is defined during this phase. Here we refer to “synthesis” activities which require a thorough understanding of higher-level problems about the product and the relevant development process (Brusoni 2005). Hence, the underlying knowledge base is considerably wide including the whole array of technological problems involved in the product development. Once the interfaces across the subsystems are explicitly described and the functionality requirements concerning each subsystem are identified, the detail design of components can begin. The detail design phase corresponds to the development of internal parameters which should meet the physical and functional interfaces described in the integral design phase. It covers “analysis” activities where engineers explore specific problems which are framed during the synthesis phase (Brusoni 2005). The knowledge base they use is rather specialized in a specific matter. At the end of this phase, detailed production drawings for each subsystem are tested and frozen. Subsystems can be manufactured according to the drawings describing every detail about the materials, techniques and tools to be used. Thus, the knowledge transferred to the manufacturing phase is considerably explicit and specialized for each subsystem and component. The manufacturing phase is followed by an integration phase during which manufactured subsystems and components are assembled into the final product with respect to the product architecture defined in the integral design phase.

In sum, complex product development process implies evolution of knowledge bases created and integrated along the phases. The relevant knowledge for each phase requires different level of interactions between the participants.

The relationship between the architect firm and the network of firms it structures depends of the nature of the organisational interface (Araujo and al. 1999; Nellore 2001; Acha and al. 2007). T Araujo, Dubois and Gadde (1999) distinguish four kinds of interfaces:

Araujo et al. (1999) propose a categorization of “supplier interfaces” on the basis of the extent of resources shared between the prime contractors and their suppliers. Here, we take up and analyze this categorization in relation to the knowledge bases shared and integrated during the complex product development process. Since the breadth and depth of knowledge bases vary depending on the phases of product development process (Ulrich & Eppinger 2003; Brusoni 2005), the extent of knowledge shared and integrated by firms varies also depending on the phase the supplier is active in (Parker et al. 2008; Wynstra et al. 2010). That’s why, we propose to distinguish the four types of supplier interfaces (Araujo et al. 1999), on the basis of timing of suppliers' involvement:

- *Interactive interfaces* are to be established when the supplier is involved during the *integral design phase*. By sharing mutually their knowledge bases, the prime contractor and the supplier discuss different technical problems in order to develop the best solutions about forms, materials, etc. The relevant knowledge base is characterized by broad higher-level problems, and includes mostly system-dependent and complex knowledge. The relevant suppliers refer to "zero-level suppliers" which interact extremely tightly with integrators and thus are difficult to be separated from the integrators on productive level.
- When the supplier gets involved in the *detailed development phase* of a component, *translation interfaces* are established. More precisely, the prime contractor determines the critical specifications about the functionality of components and transfers them to suppliers. The latter then develops the component on its own in order to meet these specifications. Hence it translates the functional description of the component into a design and manufacturing context. The extent of knowledge sharing is not as large as within the interactive interfaces. Moreover, the knowledge base involved within this phase is less system-dependant than the one needed by the integral design activities. However it is still not particularly explicit, which makes the interactions quasi-tight.
- *Specified interfaces* appear when the supplier gets involved during the *manufacturing phase* of a component by taking into account the specifications provided by the prime contractor. Prime contractor prescribes in explicit detail all the information regarding the characteristics of the component and how it is to be manufactured. The supplier then follows these directions and produces the component. Since the transferred knowledge is quite explicit and specialized on the component, the coordination between firms can be easily supported by loosely coupled relations.
- The last type of interface appears when the supplier provides standardized components to be integrated into the final product with no or little modification. This involvement is characterized by *standardized interfaces*. The supplier develops its own products independently from any specifications, and the prime contractor, like a regular buyer, chooses through "catalogues" or "off-the-shelf" the parts. Since the firms do not share at all any resources, the coordination is decoupled.

The pivot-firm articulates the translation and interactive interfaces. It develops combinatorial skills. It has the capacity to mobilize a set of internal and external resources in order to participate in the design and production take-over of a major technical sub-unit of the final product.

In configuration taking place, a firm-pivot in charge of aerostructures or avionics systems, must meet the criteria of size, financial and technological capabilities to share industrial and financial risks. The optimal configuration of subcontractors network consist in a large companies in the first level in charge of all technical and industrial homogeneous module (aero structures, electrical wiring, embedded systems ...) related with a wide network of suppliers and subcontractors. The main characteristic of the firm-pivot is to able to share the risks according to the formula, "the equipment is paid when the aircraft is sold."

In this topic, a pivot-firm is a firm that:

- Has specific competencies. These specific skills involve a homogeneous set of knowledge and know-how (avionics, aero structures, engine nacelles…), linked with the design and/or the production of major modules or of important components for the final product.

- Has combinative competencies. These skills are technical and organizational. They are said to be combinatorial because they put their holders in the position to manage the interfaces with the other participants in the design and production process, in other words the architect-integrator and the subcontractors at the lower levels.

- Participates in the co-specification of the products. In particular in an industry of complex goods, this capacity is a direct consequence of the former two. From an organizational standpoint, co-development and co-specification generates structures that encourage decreases in time frames and costs. The economic advantage of modularization – combined with outsourcing – is, again, clear in terms of reducing the transaction and contract management costs through the decrease in the number of direct partners.

- Plays the role of an architect-firm for the units that it is in charge of. The relationship between the architect-firm and the network of firms that it structures depends on the nature of the modular interfaces (Figure 1).

Figure 1: Interfaces, competencies and pivot-firms

On that basis, the “optimal” configuration for a subcontracting network would include big pivot-firms for homogeneous technical-industrial sets (aerostructues, wiring harness, embedded systems…), other smaller pivot-firms and finally suppliers and sub-contractors. The characteristic of the pivot-firms would be to share the risks according to the principle that ‘the equipment is paid for only if the aircraft is sold”.

Cagli and al. (2009) illustrate the interactions between the pivot-firms and Airbus and Boeing with examples. For instance, the Safran group, through its different subsidiaries, positions itself on a high number of strategic technical modules and components in the production of an aircraft. Through Techspace Aero, Messier-Dowti and Messier-Buggati, Safran participates in the design and production of aircrafts’ engines, wheels, brakes and landing gears. Earlier in the paper, we have seen that the components come within the strategic segmentation of Airbus’ supply chain (Figure 2).

Figure 3: Safran Group as a pivot-firm

As a pivot actor, Safran has mainly business relationships with Airbus, even if it participates to the subcontracting chain of Boeing (48 business relationships with Airbus and 24 with Boeing). Besides, if some subsidiaries of the group (Labinal, Messier Buggati and Messier-Dowty) are Boeing global partners, only Airbus considers the entire group as one of its major subcontractor. This relation with Airbus can be explained by the geographic proximity with the group's subsidiaries and by how long they have had relationships (Kechidi and Talbot 2010; Gilly et al. 2011).

6 Conclusion

Aircraft has become an increasingly complex technical object. This complexity has generated changes in the organization of aircraft manufacturing. The case of Airbus is significant in this evolution. In comparison with Boeing, it is clearly Airbus that has been able to draw the most advantages from the modularization trend of the past few years. According to us, the dynamic of technical and organisation innovation, as well as the industrial model that generated it, have played a large part in the success of Airbus on the civil aviation world markets. The industrial organisation which has progressively been put in place is characterised by:

• a refocusing of activities on the core of Airbus's business. With Power 8, Airbus has accelerated this refocusing. It has evolved from a status of "aircraft manufacturer" to the status of "architect-integrator". The position of architect-integrator, in the upstream stage (design of the aircraft) and the downstream stage (assembly of the components and liaising with airlines) of the production and commercialisation process is strategic because it enables them to control the entirety of the value chain. This control means that the technologically strategic or profitable components continue to be manufactured internally.

• the development of modularisation in aircraft manufacturing. A real technical evolution, it has been accompanied by important organisational mutations in Airbus as well in its partners.

• the outsourcing of activities deemed to be non-strategic. Outsourcing is not a new phenomenon in the politics of industrial acquisitions. The novelty is that it concerns new activities and/or involves larger volumes. As a consequence of the development of modularisation, the outsourced "technological packages" now represent systems and entire technical sets.

• the reinforcement of the role of Airbus's major partners. These firms, that produce important "technological packages", in turn play the role of architect-integrators for the sets they produce. They have the specific capacity to articulate the vertical relationships between the architect-integrator and the other (inferior) levels of sub-contracting or of supplying components and equipment. More than simple "tier one" or Risk Sharing Partnerships, these firms become essential partners in the design and manufacturing of the aircraft.

The strong outsourcing as well the international fragmentation of the production process are however important limitations on this organisational model. The difficulties encountered by Airbus for the assembly of the A380 and by Boeing for the B787 reflect the limitations of outsourcing and modularisation. The recomposition of the industrial puzzle poses real problems with regard to the management of the different technical and organisational interfaces. These problems directly affect the profitability of the projects. Indeed, according to the Seattle Times of 18 December 2010, the cost of the 787 has increased from 5 billion dollars to between 12 and 18 billion dollars.

Boeing acquiring Vought Aircraft's share of Global Aeronautica can be interpreted as a return to the internalisation of a part of the construction of the aero-structure. Similarly, Airbus keeping the manufacturing of the central box and the wings of the A350 internal is clearly a sign of the breaks being put on outsourcing. The elements which in the past pushed forward the performance of this production model seem today to be holding it back.

References

ACHA Virginia, BRUSONI Stéfano, PRINCIPE Andrea, "Exploring The Miracle: Strategy And Management Of The Knowledge Base In The Aeronautics Industry". *International Journal of Innovation Technology Management*, 2007, n°4(01), pp.15–39.

AGRAWAL Ajay, COCKBURN Iain, "The anchor tenant hypothesis: exploring the role of large, local, R-D intensive firms in Regional Innovation System", *International Journal of Industrial organization,* 2003, *n*°21(9), pp.1227-1253.

AMESSE Fernand et al., "Issues on partnering: evidences from subcontracting in aeronautics" *Technovation* , 2001, 21(9): 559–569.

ARAUJO Luis, DUBOIS Anna, GADDE Lars-Erik, "Managing interfaces with suppliers" *Industrial Marketing Management*, 1999, 28(5): 497–506.

BALDWIN Carlisse, CLARCK Kim KB " *Design rules: The power of modularity*. The MIT Press, 2000.

BRUSONI Stéfano, PRENCIPE Andrea, "Unpacking the Black Box of Modularity: Technologies, Products and Organizations" *Industrial and Corporate Change,* 2001, 10(1): 179–205.

BRESNAHAN Timothy, GREENSTEIN Shane, "Technological Competition and the Structure of the Computing Industry". *Journal of Industrial Economics*, 1999, Winter.

CAGLI Ayse, KECHIDI Med, LEVY Rachel, « Gestion stratégique de la supply chain et firme-pivot dans le secteur aéronautique », *Revue Française de Gestion Industrielle,* 2009, n°28(2), pp. 89-106.

CAGLIANO Raffaela, CANIATO Frederico, SPINA Gianluca, "Lean, Agile and Traditional Supply: How Do They Impact Manufacturing Performance?" *Journal of Purchasing and Supply Management,* 2004, *n*°10, pp. 151–164.

CAMPOS L. M. B. C, (2001) On the Competition between Airbus and Boeing, Air & Space Europe, Vol3, n°1/2, pp11-14.

CARRINCAZEAUX Christophe, FRIGANT Vincent, “The internationalization of French aerospace Industry: to what extent were the 1990s a break with the Past” *Competition and Change*, 2007, N° 11/3, pp. 260-284.

COHENDET Patrick, DIANI Morad, LERCH Christophe, « Stratégie modulaire dans la conception. Une interprétation en termes de communauté », *Revue Française de Gestion* 2005-5(158): 121-143.

COOKE Phil, EHRET Oliver, “Proximity and Procurement: A study of Agglomeration in the Welsh Aerospace Industry” *European Planning Studies*, 2009, 17(4): 549-567.

DESTEFANI John, “A look at the Boeing’s outsourcing strategy”. *Manufacturing Engineering*, 2004, n°132 (3).

EHRET Oliver, COOKE Phil, “Conceptualising aerospace outsourcing: Airbus UK and the lean supply approach”. *International Journal of Technology Management* 2010, 50(3/4): 300–317.

FRERY Frédéric, La Chaîne et le Réseau. In: Besson P (dir.), *Dedans, dehors*. Paris, Vuibert, 1997,p. 23-53.

FRIGANT Vincent, “Vanishing Hand versus Systems Integrators. Une revue de la littérature sur l’impact organisationnel de la modularité », *Revue d’économie industrielle,* 2005, 109(1er Tri): 29 – 52.

FRIGANT Vincent, KECHIDI Med, TALBOT Damien, *Les territoires de l'aéronautique EADS, entre mondialisation et ancrage territorial*. Paris, L'Harmattan, 2006.

GAMSER Matthew, “Innovation, Technical Assistance, and Development: The Importance of Technology Users” *World Development*, 1988, 16(6): 711-721.

GILLY Jean-Pierre Gilly, KECHIDI Med, TALBOT Damien, Resilience of organisations and territories: the role of pivot firms, *European Management Journal*, 2014, Vol 32, N° 4.

GILLY Jean-Pierre P, TALBOT Damien ZULIANI Jean-Marc, “Firms Hub and the Dynamics of Regional Innovation: Case Studies of Thales and Liebherr in Toulouse” *European Planning Studies*, 2011, 19(12): 2009-2024.

GIVON Moshé, RIETVELD Piet, “Airline’s choice of aircraft size. Explanations and implications”, Transportation Research, Vol. 43, Issue 5, pp 500-510.

HOWARD Mickey, SQUIER Brian, “Modularization and the impact on supply relationships”, *International Journal of Operations & Production Management*, 2007, 27(11), 1192 - 1212.

JARILLO Juan Carlos, “On strategic Networks” *Strategic Management Journal*, 1988, 9: 31-41.

KECHIDI Med, « Coordination inter-entreprises et relations de sous-traitance: le cas d’Aérospatiale » *Revue d’Economie Régionale et Urbaine*,1996, N° 1: pp. 99-120.

KECHIDI Med, « Les relations verticales dans l’industrie aéronautique : le cas de la sous-traitance d’Airbus France » *Revue Française de Gestion Industrielle*, 2006, N°25(2): pp. 21-40

LANGLOIS Richard, “Modularity in Technology and organization” *Journal Of Economic Behavior & Organization*, 2002, n°49, pp. 19-37.

LANGLOIS Richard, The vanishing hand: the changing dynamics of industrial capitalism. Industrial and Corporate Change 2003,n°12(2), pp. 351-385.

LANGLOIS Richard, ROBERTSON Paul, “Networks and innovation in a modular system: Lessons from the microcomputer and stereo component industries” *Research Policy*, 1992, n°21(4):pp. 297-313.

LAWRENCE Philip, THORNTON David, *Deep stall, The turbulent story of Boeing commercial airplanes*. Routledge, 2005.

MITLETON-KELLY. *Complex systems and evolutionary perspectives on organisations: the application of complexity theory to organisations*, Emerald Group Pub Ltd. 2003.

MULLER Pierre. *Logique d'Etat, logique de marché,* Paris, L'Harmattan, 1989.

NELLORE Rajesh, “The impact of supplier visions on product development”, *Journal of Supply Chain Management* 2001, n°37(1), pp.27-36.

NIOSI Jorge , ZHEGU Majlinda, “Anchor tenants and regional innovation systems: the aircraft industry”. *International Journal of Technology Management,* 2010, n°50(3/4), pp. 263-284.

NOLAN Peter, ZHANG Jin, “The Challenge of Globalization for Large Chinese Firms”. *World Development,* 2002, n°30(12), pp.2089-2107.

PARKER, D. B., ZSIDISIN, G. A., & RAGATZ agatz, G. L., « Timing and extent of supplier integration in new product development: a contingency approach ». *Journal of Supply Chain Management,* 2008, 44(1), 71-83.

ROSE-ANDERSSEN Christien, BALDWIN James, RIDGWAY Keith, ALLEN Peter, VARGA Liz, STRATHERN Mark, “A cladistic classification of commercial aerospace supply chain evolution”, *Journal of Manufacturing Technology Management*, 2009, n°20(Issue 2), pp. 235 – 25.

ROSE-ANDERSSEN Christien, BALDWIN James, RIDGWAY Keith, ALLEN Peter, VARGA Liz, “Aerospace Supply Chains as Evolutionary Networks of Activities: Innovation via Risk-Sharing Partnerships”, *Creativity and Innovation Management* 2008, n°17(Issue 4), pp. pp.304-318.

SANCHEZ Ron, MAHONEY Joseph, “Modularity, flexibility, and knowledge management in product and organization design” *Strategic management journal*, 199617 Special issue (winter)): 63–76.

SIMON Herbert () “The architecture Of Complexity”, *Proceedings Of The American Philosophical* 1962, n°106(6), pp. 467-482.

TALBOT Damien “Institutional dynamics and localized inter-firm relations: the case of Aérospatiale and its subcontractors in Toulouse”, *European Urban and Regional Studies*, 2000, n°7(3), pp.223-236.

ULRICH Karl, “The role of product architecture in the manufacturing firm”, *Research policy* 1995, n°24(3), pp.419–440.

ULRICH Karl, EPPINGER Steven, *Product Design and Development*, 4th edition, McGraw-Hill/Irwin, 2008.

ZULIANI Jean-Marc, “Chapitre 4: Le système industriel des hautes technologies et de l’innovation: trajectoires récentes” in ESCARFFE Fabrice et JAILLET Marie-Christine (dirs.), *Une trajectoire métropolitaine. L’exemple de Toulouse*, Le Moniteur, 2016, pp131-180.