



HAL
open science

Technological Determinism and Modularity: Lessons from a Comparison between Aircraft and Auto Industries in Europe

Vincent Frigant, Damien Talbot

► **To cite this version:**

Vincent Frigant, Damien Talbot. Technological Determinism and Modularity: Lessons from a Comparison between Aircraft and Auto Industries in Europe. *Industry and Innovation*, 2005, 12 (3), pp.337-355. 10.1080/13662710500195934 . hal-04612783

HAL Id: hal-04612783

<https://hal.science/hal-04612783v1>

Submitted on 14 Jun 2024

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

TECHNOLOGICAL DETERMINISM AND MODULARITY: LESSONS
FROM A COMPARISON BETWEEN AIRCRAFT AND AUTO
INDUSTRIES IN EUROPE

INDUSTRY AND INNOVATION,
VOL. 12, NO. 3, 337–355, SEPTEMBER 2005

Vincent FRIGANT* and Damien TALBOT

(* corresponding author)

E3i
IFReDE - GRES
University of Montesquieu-Bordeaux IV
Avenue Léon Duguit
F-33608 PESSAC Cedex

E-mail : frigant@bordeaux4.fr
talbot@u-bordeaux4.fr
Tel. : +33.5.56.84.25.75
Fax. : +33.5.56.84.86.47

Vincent Frigant is a maître de conférences (reader) in economics at Team Industries-Innovation-Institutions (E3i) of the Federative Institute for Research on Economic Dynamics (IFReDE), University of Montesquieu-Bordeaux IV. He is a member of the GERPISA-International Network. His research deals with industrial dynamics and organisational change at corporate and industrial level. His current research focuses on modular production in the aircraft and auto industries and on globalisation of First-Tier Suppliers. He can be contacted at frigant@u-bordeaux4.fr.

Damien Talbot is a maître de conférences (reader) in management at Team Industries-Innovation-Institutions (E3i) of the Federative Institute for Research on Economic Dynamics (IFReDE), University of Montesquieu-Bordeaux IV. His research focuses on the explanations of the dynamics of production relationships between an industrial group and its subcontractors. More precisely, he intends to analyse the evolution of *local* subcontracting relationships. His field of analysis is mainly in the sector of civil aeronautics. He can be contacted at talbot@u-bordeaux4.fr.

TECHNOLOGICAL DETERMINISM AND MODULARITY: LESSONS FROM A COMPARISON BETWEEN AIRCRAFT AND AUTO INDUSTRIES IN EUROPE

Abstract: Initial studies of modular manufacturing processes have shown that this dominant design required a fundamentally novel organisational structure of the industries. The underlying hypothesis of technological determinism merits a deeper exploration. The first part of the present paper aims at presenting the logic of this argument while making a distinction between the technological and organisational aspects of modularity. Based on this we then attempt a study of the manner in which the transition to modularity takes place in the aircraft and automobile industries. Our main conclusion is that while it may be possible to posit a convergence between these two industries, the paths followed are still quite clearly opposed.

Key-Words: Modular Production, Supplier Relationships, Technological determinism, Aircraft, Automobile.

JEL : L22, L23, L62, M11

The management of complexity is a crucial issue in the assembly industries. Even if this problem is an old one, it has become much more acute in recent years: technological innovations, competition through innovation, the fusion of dissimilar technologies are all elements which increase the complexity of the design and manufacture of products. In one of his last articles, the late K. Pavitt (2003) stressed that modular design is a response to handle the growing complexity of products and multi-technology products. Beyond this, the heart of his article is to be found in the critical discussion of the thesis by which modular design leads to a kind of Legoland.

In fact, a number of works on the organisational impact of modularity have approached the problem from two distinct angles (see Ernst, 2005; Frigant, 2005). The first stressed primarily, by taking as examples the electronic and computer industries, that modularity favours vertical disintegration (Langlois, 2002; Sanchez, 2000; Sturgeon, 2002; Baldwin, Clark, 2000; on the bicycle industry, see Galvin and Morkel, 2001). Their argument is based on the idea that the standardisation of interfaces enables an increase in outsourcing and reliance on market-coordinated First-Tier Suppliers (FTSs). This is in line with the Vanishing Hand hypothesis advanced by R. Langlois (2003). Nevertheless, several more recent authors have insisted on the sectorial specificity of these conclusions. They point out that the modularisation of the Complex Products Systems (COPS) requires knowledge in a large field of specific areas, and that, if outsourcing is possible, it entails close relations with the suppliers. (cf. Prencipe, Davies, Hobday, 2003)

If the conclusions of these works seem quite disparate, they do have one implicit hypothesis in common: it is the technologies – characterising the products studied – which determine the relevant organisational forms. The efficiency of the technology/organisation couples examined stems from the competencies necessary for the manufacture of the product, which, in turn, necessitate special organisation. The characteristics of the products considered being technologically different, the organisations they entail are also different¹.

¹ We can illustrate this point by this citation of Andrea Prencipe about the two approaches: “Modular networks of production are the appropriate organizational arrangements in situations where products are characterized by even rates of change among component technologies and predictable interdependencies at the product level. Such modular networks are coordinated via arm’s-length market relationships. (...) Products characterized by both component technologies changing at uneven rates and by unpredictable interdependencies across components require large, integrated firms to maintain in-house both the knowledge and the activities involved in the design and production of their final products and component units” (Prencipe, 2003, 128-29).

In this article we hope to explore again this technology/organisation relationship by following a different hypothesis. It appears to us that most of the existing works are searching for a clear causal link between organisation and technology. However, such research (although useful, necessary and rewarding) tends to emphasise the synchronic aspect of the modifications between technology and organisation. By doing this, it also associates, two by two, a type of product with an organisational design, the first tending to explain, almost exclusively according to the authors, the second.

Here we are going to start from an alternative hypothesis, which we have chosen in order to provoke but which we feel is also heuristically rich, by supposing that there are two modularities; a technological modularity and an organisational modularity. In addition we suppose that the two modularities can exist separately at least for a certain time. Starting from these two hypotheses, our research consisted in retracing the trajectory of the adoption of modularity in industry. So what we are in fact aiming to do is to stress the diachronic dimension of the passage to modularity. The interest of this method is that it should, if need be, allow us to establish if technological modularity (always) precedes organisational modularity, which would validate the theory of a form of technological determinism.

This paper is of an exploratory nature, so we will limit our analysis to the study of two industries. The two industries compared are the auto and aircraft industries (mainly European) which have the reputation of having recently “discovered” modularity. In methodological terms, we will reason using stylised facts because our aim is just to illustrate our theoretical claims. Indeed these two examples suggest to reconsider the thesis of technological determinism.

The paper is organised into two parts. The first part deals with the definition of modular production which is seen as a new matrix of a coherent model for the organisation of supplier relationships. It is a coherence which depends upon the setting up of an appropriate technology/organisation couple. We will then present, by the means of stylised facts, the manner in which the automobile and aircraft industries made an attempt towards modularity by making a distinction between its dual dimensions – technology and organisation. Finally, these two examples will serve to underline the fact that in its modes of adoption, modularity is a complex phenomenon and that the question of technological or organisational determinism remains open.

MODULARITY: FROM A TECHNOLOGICAL TO AN ORGANISATIONAL ARCHITECTURE

In the literature, modular production consists of two, intrinsically linked dimensions. To begin with, it is a method of conceiving and producing a good – which harks back to the dimension of technology, but it also has in equal measure the organisational dimension which would justify the economist's interest. Most of the studies on this subject support the view that there come about an isomorphism between the technological structure induced by the adoption of modularity and the organisational structure required to implement the production of modular goods. We will run rapidly through this literature in order to clarify the two notions of modularity, technological and organisational, which we will then use as a key to understand our history of the two industries.

Modularity as a product design

Fundamentally, modularity is the result of a need and the effort to break down complex systems. It consists of splitting a final product into a group of subsets, be they simple or complex, which are then inter-linked via standardised interfaces. The game of Lego® can serve as an example: every element of the game is a module whose interfaces, the tenons and mortises, are standardised and which thus allow the element to be integrated, irrespective of its form, into a complex system. We see then that from the moment the shape of every module, and especially the interfaces, are fixed, the concept of modularity allows a large variety in the assembly. Obviously, in the case of industrial products, the process will be much more complicated as it entails starting from the result (the final product is presumed to be a complex system) and of specifying the modules and their interactions with the aim of arriving at a (series of) global function(s).

To the extent that every module can, in itself, be a combination of different physical components, a definition of modularity can be seen in terms of product architecture (Ulrich, 1995). The product architecture is the manner in which all the functional elements and the physical components of a global system (the product) are arranged. Therefore, to specify the architecture of a product would mean to identify:

- i. the manner in which the different functional elements of the complex system are fitted together. This design will determine the global performance of the product.

ii. the manner in which these functional elements are transposed into physical components. It is these latter which are integrated concretely in the product. The essential question here is to know whether a function must/can be fulfilled by one or more components.

iii. the manner in which the components are linked to each other and to the global system. The question devolves then to the interfaces which govern the physical interactions between the components. In the case where a modification of a component implies a consequent modification to a linked component, the interface is termed coupled. Conversely, interfaces are called de-coupled if a change in a component does not imply a subsequent change in the other.

Henceforth, an architecture is designated as modular if there exists, on one hand, an identity between the physical component and the function and, on the other hand, a de-coupling of the interfaces which link the components. Inversely, product architecture is termed “integral” when a physical component cannot be associated to a function and/or the interfaces are coupled.

The de-coupling of interfaces is of prime importance because it means that every individual module can be developed, pre-assembled and modified separately, without any consequent modification of other modules or a re-defining of the product as a whole. Thus, the implementation of a modular architecture is often sought when new functionalities or technologies are to be introduced in a given product and we can well understand the interest in modularity evinced by firms within those sectors in which:

- The competitiveness depends on product differentiation, for example, in the automobile industry.
- The life of the product is particularly long and/or the running conditions are severe which aggravate maintenance problems and/or require upgrading programs, like in the aircraft industry.
- The regulations and technology concerning some functions of the product are variable and evolving.

In effect, a modular architecture makes it that much easier to realize incremental modifications of a product over its service life. R. Langlois and P. Robertson (1992) have shown how, in the electronics industry, a product is re-adapted *ex post* to suit the requirements expressed subsequently by the market well after its initial launch. Broadly speaking, modularity allows an increase in the number of variants (models) of a product within the framework of a strategy for offering multi-options (Schaefer, 1999) while reducing

the time-to-market, thanks to a reduction in the delays regarding the designing of the modules (Ulrich, 1995; Sussman, Guinan, 1999; Baldwin, Clark, 2000). Still, to be able to take advantage of these opportunities requires the existence of an adequate organisation (Sanchez, Mahoney, 1996): an efficient implementation of a modular product architecture needs an equally modular organisation.

The organisational dimension of modularity

Modularity contains within itself the seeds of deepening the division of labour in the sense that the modular product architecture entails a decoupling of tasks, in concept and in production, on each module taken separately. Thus, under the weight of factors which lead to a vertical disintegration, the large vertically integrated corporation will fall apart (Langlois, 2003) and result in an organisational structure which we term “modular”.

This vertical disintegration has its roots in the simplification of the interlinking components related to the development, the production and the modification of the product. In a strictly modular architecture two key agents exist. The first is the architect of the product. His function is to define the general characteristics of the product and to specify the interfaces. The second agent consists in the development and production of the modules.

The essential point is that the architect need not know the intrinsic characteristics of the modules. In this context, Baldwin and Clark (2000) have introduced a useful distinction between the visible and invisible elements. The role of the architect is limited to defining the visible elements of the system. He is concerned only with the meeting points between the components, that is to say, the interfaces and the functional and physical specifications (size, weight) which have been allocated to the modules. Thus, the actual content of the module, be it the physical arrangement of its components (and their intrinsic properties) or the functional arrangement of the sub-systems incorporated in the module, can remain invisible. In other words, all the teams related to the development of the product need not have the entire set of information to accomplish their specific tasks. Henceforth, modularity would promote a division of labour between teams, at least in the case of detailed decisions regarding a particular functionality or material.

Thus, modularity seeks to bring together task specialization and the autonomy of the teams involved in the conception/production. This would result in an increase in the efficiency of the value chain, mainly by accelerating the process of the exploitation of the dynamic learning of competencies which have now become more focused (Sanchez, Mahoney, 1996; Brusoni,

Prencipe, 2001). For that, the architect must have all the knowledge concerning the definition of the product architecture – especially the technical know-how related to, on one hand, the functions of the modules by themselves and, on the other, the identification of their interactions. Moreover, he must also be market-savvy so as to be able to come up with commercially viable products. As for the teams in charge of the modules, they must refocus themselves only on those competencies which bear directly on the production of the particular elements they have been given charge of.

Moreover, to the extent in which the coordination can, *theoretically*, be achieved by the use of relatively simple communication channels based on information technology, modularity will also influence the balance between the division and centralization of the tasks stemming from the cost constraints associated with the transmission, reception and processing of information (Sanchez, 2000). These channels link the decision-making hubs – in terms of the conception of the product design – to the units concerned with development and production. Even in cases where information technology is found inadequate to bring about a cognitive coordination, the minimizing of the quantity of information to be spread (visible elements) and the re-utilization of existing modules would ensure that the implementation of more complex systems, such as project teams, should be possible more easily and cheaply through modularity than in the case of an integral architecture. The simplification of the coordinating processes on the cognitive dimension – combined with the dynamics of a competitiveness which results from the competition between different module suppliers – favours a vertical disintegration (Sturgeon, 2002).

At this point in the discussion, we can begin to see an opposition between the works close to the Vanishing Hand (Langlois 2003) and those close to the Integrator Systems (Brusoni Prencipe, 2001; Prencipe, Davies, Hobday, 2003). Whereas in the first case, the claim is made that vertical disintegration is largely possible and that it is possible to manage First-Tier Suppliers via arm's-length market relationships, in the second, it is claimed that firms should keep a large part of their competencies in-house and that outsourcing, when it is possible, entails close relationships between suppliers and buyers.

Above and beyond this debate on the concrete form of modularity, it appears to us that these approaches point to the characterisation of organisational modularity as being based on three principles. We are also proposing a topological definition of organisational modularity.

This definition is compatible with the two approaches as it characterises the key elements of modularity and not the effective content of its form².

With this firmly in mind, the modular product architecture induces the formation of an equally modular organisational architecture, in which:

- the seller of the final product is the product architect and drives a network of module suppliers. This architect could be a virtual firm or an integrator system according to the authors (eg. Langlois 2003 vs Prencipe 2003).

- “organisational modules” emerge wherein suppliers at different levels upstream of the production process take charge of the production of modules (in the technical sense, i.e. the sub-systems). There again, the responsibility of the suppliers could vary depending on the approach chosen: total responsibility for the module from design to after-sales-service vs sub-contracting with the customer being heavily involved.

- “organisational interfaces” are formed: they correspond to the various processes of inter-firms coordination implemented. Here we find again the opposition between arms length relationships and complex forms of cognitive and contractual coordination.

Finally, modularity stems from two intimately linked factors: an engineering process which seeks to reduce the complexity of the technical systems and an organisational restructuring so as to take advantage of the opportunities to further agent specialization. While the computer (Baldwin, Clark, 2000; Sturgeon, 2002), electronics (Langlois, Robertson, 1992) and bicycle (Galvin, Morkel, 2001) industries have become the pioneers in exploiting this double opportunity, there are a number of others looking to jump onto this bandwagon. Still, as we shall presently see in the case of the aircraft and automobile industries, the paths differ from industry to industry.

THE ADOPTION OF MODULARITY IN THE CIVIL AIRCRAFT AND AUTOMOBILE IN EUROPE

The advantages of a modular architecture over an integral architecture enticed a number of firms. Industries which had hardly been affected by this type of product design, have sought, for some years now, to restructure accordingly. The European aircraft and automobile industries are two such industries. Still, the adoption of such an architecture required a process of transformation rendered doubly complex by the fact that it involved a dual

² Obviously these three principles must be made consistent. It is hardly foreseeable to become virtual and to claim to deal with one's suppliers in a productive and cognitive manner.

approach, in the technological and the organisational dimensions, dealing with the whole scope of the creation of resources (conception/production/distribution, intra- and inter-firm). Consequently, the transition to modularity followed differing trajectories depending on the initial situation of the industries – be it their architectural configurations or the balance of power between the different firms involved in this process of adoption. Thus in practice, the transition to modularity in the civil aircraft and auto industries of Europe differed significantly in both the technological and organisational dimensions.

Civil aircraft: an established technological dimension, an organisational dimension still in the process of emerging

The aircraft: a product family

From a technological point of view, the complexity of the process behind the design and production of an aircraft may be judged by the number of components required for it to fly: an Airbus has more than two million parts (including rivets). Very early, aircraft manufacturers, sought to reduce this complexity by dividing the aircraft into a series of relatively independent modules linked by more or less standardised and stable interfaces.

If this is the objective, two vital elements will allow the transition to take place and at the same time explain why modular design will start to emerge, especially in Europe. The first factor is political and stems from the desire to create an aircraft manufacturer (Airbus) to compete with Boeing. As the various national companies, members of the Airbus consortium, needed to cooperate and harmonise the use of their skills, the engineers looked for ways to reduce the airplane to modules so that each country was allocated a part of its design and manufacture. To this first factor, which started the ball rolling in a certain way, we must add the early choice of Airbus to use electronic controls. By suppressing a large part of the mechanical and hydraulic connections at the heart of the plane, the engineers would be able to develop the modular architecture of the product. The technological and commercial success of the Airbus models will now help to kick-start a new dominant design process in the industry and from now on it will be possible to subdivide an aircraft into a few main modules with clearly defined functions (each of which can be further broken down into sub-modules). At every stage, we give an example of a so-called “decoupled” interface, which could be either mechanical or electronic:

- the avionics consists of the integration of the navigation and the flight control systems. It is the heart of the aircraft and has a large number of interfaces, like the flight control system and the electric power supply.
- various modules such as the fuselage (itself divided into sections), the horizontal and vertical empennages or the wings themselves – all of which constitute the physical body of the product and which are linked to each other by simple mechanical attachments.
- the engines, which are attached to the wings by the means of engine pods and pylons with the help of mechanical and electric connections.
- the landing gear, attached directly to the fuselage.

Based on such a modular (product) architecture, Airbus and Boeing have each developed a range of large, 100-seater-plus aircraft within which every model shares some modules with the others. The same was done by Dassault for its Falcon business-jet aircraft which are also available in a wide range. It requires the design, the production, the assembly and the operation of relatively similar aircraft while keeping an eye on the requisite product diversity (Salvador *et al.*, 2002). Thus the A318/A319/A320/A321 and A330/A340 have the same instrument panel, the same piloting procedures, the same avionics and the same systems. There is practically no difference in the cockpits. The wings of the A318/A319/A320/A321 are all identical, only the length of the fuselage (and consequently the number of seats) differs. The same principle has been applied for the A330/A340 with the number of engines also being variable (from two to four). Finally, all the latest aircraft have the option to be fitted with two or even three different engines made by different engine manufacturers so as to meet the varied operational requirements of the airlines. This entails a standardization of the interfaces between the engine modules and the nacelles (Bonaccorsi, Giuri, 2001). In contrast, first generation commercial jets, like the B707, the DC-8 or the Caravelle (from the French firm *Aerospatiale*), had no such choice. Also, thanks to modularity, first Airbus and then Boeing have developed the concept of a “Family”, within which the product architecture and various interfaces are shared by all the models. The models themselves are the result of changing a few modules (Erens, Verhulst, 1997; Frenken, 2000). Such a concept has the advantage of allowing the development of any sub-system without having to re-define the entire product. Such a program can extend over forty years, going through sometimes even major technological transformations (though analytically incremental in the sense of Henderson, Clark, 1990), without having to change the initial product design. The B747 is a case in point.

The organisational dimension: the aircraft manufacturer, from an integral architect to a modular one?

Traditionally, the supplier relationships in the aircraft industry formed a closed supply chain in the sense that the aircraft manufacturer attracted a network of sub-contractors. The same held true at the level of designing, where the manufacturer became the focal point of the supply chain. In fact, he designed the overall definition of the aircraft and detailed its sub-assemblies in-house. For a long time, being an aircraft manufacturer meant mastering the value chain in its entirety, including the production methods. The external tasks were based on a list of specifications in which not only the complete product specifications, but also the operating methods were pre-defined by the buyer.

Towards the end of the 1980s, aircraft manufacturers began to question this model: speciality sub-contracting increased, the qualification requirements turned more organisational (quality certification, financial liquidity) and the specifications more functional. These developments though, should not hide the fact that apart from a few rare exceptions, notably concerning the onboard electronics, the aircraft manufacturer remained the focus of a network of sub-contractors which only just tended towards a more pyramidal structure (reduction in the number of suppliers, widening of the selection criteria, and purchase of sub-assemblies instead of simple components). The manufacturer still retained his predominance, especially regarding the detailed definitions of the sub-assemblies whose design he delegated only marginally. Despite the modular nature of the aircraft, it was a clearly centralized structure in which the manufacturer almost exclusively controlled the design in-house (Talbot, 2000).

At present, several factors have caused the appearance of a new stage in the development of the major programs. Firstly, the aircraft itself has undergone a profound change. The importance, quantitative as well as qualitative, of the aircraft's industrial component (the airframe) has diminished in comparison with the systems (Kechidi, 1996): a manufacturer can no longer keep up with the entire set of systems due to the vast range of dissimilar skills that now requires. At the same time, he must strive to refocus on his core skills and to limit himself to the role of designing and assembling the structural components. Next, there arises the question of technological and organisational learning. At the technological level, the centralization of the competencies in the hands of the manufacturers has furthered the knowledge of the systemic complexity of the product and of the interfaces between the principal modules. As the technology has more or less stabilized itself and the systemic

complexity of the product is better understood by the architect, these competencies now allow the outsourcing of modules (*cf.* Brusoni, Prencipe, Pavitt, 2001 on engine). Added to this is the fact that at the organisational level, the increase in the delegation begun in the 1990s has allowed the suppliers to develop their own competencies regarding design while at the same time it developed learning in cooperative work all along the value chain. Thirdly, in order to support the ever increasing R&D expenses in the face of the limited traditional financial sources (from the State in particular), the manufacturers sought to save time and money right from the developmental phase of the product all the way to the after-sales service (Haas, Larré, Ourtau, 2001): the mobilisation of the resources in the hands of the suppliers became the primary objective. Moreover, the inclusion in the programmes of parts manufacturers' from various countries as partners (at risk) facilitates access to relatively closed markets. If historically Boeing outsourced very little to non-American suppliers, today this is no longer the case: the inclusion of the Japanese aeronautical industry in the 7^{E7} programme to the tune of 35% contributed to the two major national companies placing orders for this new model. The European constructor has adopted a similar strategy, but with China: by sub-contracting at least 5% of the new A350 programme to the Chinese parts manufacturers (as is already the case for the A380 and the A330/340), the manufacturer expects orders in return. As we can see, apart from risk-sharing, externalisation through the modular product becomes attractive on a commercial level.

It was in this context that the transition which we call “modular organisation” came about. Whether at Airbus or other aircraft manufacturers, in France (Dassault) or elsewhere (AECMA, 2002; Amesse *et al.*, 2001), we can see a reshuffling of the supply chains whose general traits are: 1) a drastic reduction in the number of direct suppliers, 2) the selected suppliers being given the entire responsibility for the design and production of the modules that are entrusted to them and 3) a general distribution of risk-sharing. The development of the new A380 from Airbus and Dassault's Falcon 7X are fine examples of these new tendencies regarding allocation of intra- and inter-firms tasks. In both these programs, the manufacturers greatly increased the responsibilities entrusted to the First-Tier Suppliers (FTSs). The aircraft were divided into a small number of modules and the entire responsibility for each of them, in design as well as production, was borne by the designated FTS. In the case of Airbus, it is estimated that the A380's components were supplied by no more than some 50 FTSs who also bore 30% of the 10 billion Euros which went in the R&D (Haas, Larré, Ourtau, 2001).

Henceforth, to have direct access to a manufacturer would mean to participate in the financing of the R&D costs and to shoulder these responsibilities until the aircraft is certified. This in turn signified that the FTSs found themselves totally autonomous in the technological and productive dimensions, especially regarding their operational methods in order to deliver the results required of them. In this respect, the manufacturer must outsource the modules which he will subsequently receive pre-assembled, guaranteed and monitored. Moreover, the material and intangible investments would be spread over a precise number of aircraft (250 in the case of the A380) – with the work load being taken up entirely by the FTSs. The FTSs could hope to see any profit only after this quantity had been produced.

This trend towards outsourcing and the resulting division of competencies required the establishment of an elaborate system of collective coordination which would enable the manufacturer to control the entire process of design and production. Further, the system draws its coherence from a harmonisation of the design tools (the CAD/CAM platform and software), the introduction of concurrent engineering and a homogenization of training and documentation. The whole process is supplemented by the formation of project teams comprised of a mixed workforce from both the manufacturer and his FTSs. This transformation is well illustrated in the development of the A340-500/600 in 1997 when Airbus formed its first mixed team. The process was furthered in the A380 with the formation of a team of a thousand engineers and technicians at Toulouse where personnel from both the manufacturer and the suppliers came together. This also meant a coherent logistic solution: the flow of inputs was assured by the implementation of an entire information network between the different manufacturing sites and the principal suppliers. These changes though, were more in the nature of a development than a breakdown, as an information network had already begun to emerge towards the end of the previous decade when Aerospatiale had sought to connect all its sub-contractors in a bid to introduce just-in-time delivery. The supply schedules and delivery calls were generated automatically and transmitted to the suppliers via Electronic Data Interchange (EDI).

On the whole, the complexity of the product and the resulting need to outsource the design and production of some modules required the architect to have a clear idea of the technological and organisational aspects of all interfaces. The examples of civil aircraft industry and of Airbus in particular, highlight the fact that the adoption of a modular product architecture results in the adoption of an equally modular organisational architecture where, around the designer/assembler of airframes:

- There arises on one hand a network of FTSs whose job it is to design and manufacture modules in their entirety.
- And, on the other, diverse organisational interfaces (concurrent engineering and mixed design teams, data regarding the flows of product) are implemented.

In this sense, the aircraft industry is a good illustration of the hypothesis of a form of technological determinism where the modular design forces the organisation to be adapted, even if we have seen that the political dimension (the desire to create Airbus) played a key role in the initial movement towards technological modularity. Subsequently, the growing complexity of products encouraged the adoption of a modular organisational structure in line with the continuation of work in terms of the Complex Product Systems

Modularity in the European auto industry: an established organisational dimension, an emerging technological dimension

If the automobile doesn't seem to have evolved much since its creation, the industry itself has undergone a substantial change with major innovations in the product as well as the process (Hatchuel *et al.*, 2002). Now, modular production seems to be at the heart of the car makers' agenda (Volpato, 2004). But any resemblance with the aircraft industry stops there. In fact, going by our classification based on the technology/organisation couple, the adoption of modularity follows a completely opposite path. While the modularity in the automobile industry seems already in place globally at the organizational level, the crucial point for it remains in breaking down the product technologically into a set of consistent modules.

The technological dimension: the automobile, a future modular product?

The first automobiles made at the beginning of the 20th century were the result of a modular process (McAlinden *et alii*, 1999). Neither wholly craftsmen, nor fully industrialized, auto manufacturers were product architects whose job was to design the vehicle and assemble the components which were bought externally. Then, the transition to mass production brought about a change in their function. The opportunities offered by the economies of scale and the limitations imposed on one hand by an increasingly complex supply chain, and on the other, the rising demands of consumers regarding the quality of the product (comfort, functionality) justified an initial reconfiguration of the manufacturing process around an integrated corporation and an integral product.

A modern car is the result of assembling some 15 000 to 20 000 components (depending on the model) of varied sizes and costs which together fulfil specific functions (accommodate/protect: the body, drive: the engine transmission unit, etc.) and which, at final assembly make up the vehicle (Chanaron, Lung, 1995). The essential difference from an aircraft is two-fold: the identity between component and function is weaker and the interfaces unstable and reworked from one model to another. Thus the road-holding qualities depend on a multitude of parameters (wheelbase, aerodynamics, propulsion) which require specific solutions to every model regarding the sub-systems which ensure road handling (type of tyre, shock absorber, front and rear suspension, etc.). The result being that the car is the product of a system which is itself made up of sub-systems which have the distinction of being physically unconnected (Sako, 2000).

One of the tricky problems in the transition to the modular design results from this separation. In fact, the functional sub-systems are often located over several sites of the vehicle. Thus, the braking system involves elements in the cockpit, the front and rear suspensions, not to speak of the components which transmit the brake command and the electronic chips which are distributed throughout the vehicle. In such a situation, a transition to modularity must overcome a double difficulty.

First, to be able to divide and re-assemble the vehicle around modules which, though never quite corresponding to a pure modular architecture in the sense of Ulrich (1995) would be physically integrated into multi-functional physical sub-systems. The engineers try to redefine the vehicle as a collection of compact, physical assemblies: the chassis, the wheel-tyre set, the cockpit... Nevertheless, the solutions adopted remain individual for the moment. From one manufacturer to another, the way of thinking about modularity is different (Gadde, Jelbo, 2002). As opposed to the aeronautical industry, no dominant design exists, just local solutions. The diversity of the solutions is explained by the second difficulty: the constraint caused by respect for the integrity of the product (Clark, Fujimoto, 1991). This constraint is difficult to respect because a car requires numerous mechanical and hydraulic connections. It is consequently difficult to associate the modules with particular functions, and, with each new model, all the modules need to be redefined and their respective compatibility tested. Here, the change to electronic controls could offer new possibilities. This dependence on technological progress is exemplified in the case of airbags which could only 'become a module' when progress in electronics allowed their miniaturisation (Velooso, Fixon, 2001). What is more, this latter is far more important in the car than in the airplane due to the fact

that usage is so much more varied and driving methods so much more diverse. Despite these technical difficulties, modularity began to assume a vital role due to the very nature of the industry's organisation which pushed for its adoption.

The organisational dimension: the product architecture defined by the organisation

The transformations described above, at the organisational level within the aircraft industry, appear more clearly and spread more widely over a longer period in the auto industry. Right from the mid 80s, it was well noted that one of the key ingredients which rendered the Japanese car-makers so competitive was their system of organising supplier relationships (Asanuma, 1993). Faced by the prospects of a growing free market, European automakers adopted Japanese methods by hybridization (Boyer *et alii*, 1998). It resulted in a surge in outsourcing, a drastic reduction in the number of suppliers and greater selectivity. At the same time, manufacturers also pushed towards a greater delegation of the design process, even though at that time, it was more like co-designing than a complete outsourcing (Lung, Volpato, 2002).

The supplier relationships in the automobile industry organised themselves much more rapidly in a pyramidal form than those in the aircraft industry. Today, the value chain is comprised of an international network of First-Tier Suppliers (FTSs) who collaborate with manufacturers to produce the whole range of models. These FTSs look after the entire process of design and production of sub-systems and, in a new turn of events, even propose and offer technological alternatives and options to the manufacturers. The automakers have found themselves completely distanced from any detailed designing and have had to cut all relevant departments internally. Clearly, their aim now is to refocus themselves on their main job: to define the global architecture of automobiles and their market positioning (Lung, 2004).

Considering the systemic nature of automobiles, it should come as no surprise that, over the course of the development of their relations built across multiple locations and interface procedures, the companies began to overlap and intermingle organisationally. The coherence of the final product required a focused cognitive coordination throughout the design and production phases. The methods of concurrent engineering spread and lead to a very clear division of labour among the numerous teams. Thus, the setting up of project teams which brought together the suppliers and the buyer helped in the revival of the disintegrating firm (Segrestin, Lefebvre, Weil, 2002). Moreover, the generalization of EDI and the ever-increasing reliance on transporters, who had become the actual managers of the physical flow

of products, facilitated a tight coordination of the supply chain. Nevertheless, the *just-in-sequence* implied by modularity in the context of large and fragile modules often meant that a need arose for the spatial concentration of suppliers close to the manufacturers' assembly factories so as to ensure steady and safe deliveries. At the same time, this spatial concentration improved interfirm coordination while creating a credible bilateral commitment and enhancing outsourcing efficiency (Frigant, Lung, 2002).

Finally, over the years, this movement towards 1) automakers as architects, 2) delegation of responsibility to FTSs and 3) closed vertical relationship, brought about a change in the industry, bringing it nearer to a modular organisational architecture. Thus, in spite of all the difficulties (*cf. supra*), the act of developing a modular product architecture resulted in a similar organisation: modularity is found where the interests of the manufacturers and the suppliers converge.

From the automakers' point of view, the advantages include a greater range of model variants, and the possibility of adopting build-to-order, while at the same time reducing development delays and the locking up of capital. Concerning this latter point especially, modularity offers the clear opportunity of managing financial constraints by transforming the fixed costs into variable ones via outsourcing (Salerno, 2001). As with the aircraft industry, modularity in the auto industry offers a means of managing the rising number and complexity of the competencies required for the implementation of newer technology in the car, as demanded by an increasingly more competitive environment (the ever-growing use of electronics, for example) and more stringent regulations (zero-emission technology) (Volpato, 2004). The incompatibility between the need to focus on competencies on one hand, and the necessity of expanding the knowledge-base on the other, calls for suppliers of specialized modules who would benefit more by the economies of scale and learning due to the fact that they would supply relatively standardized modules to several automakers.

On the other hand, the FTSs have the opportunity to grab a larger share of the relational quasi-rent (Asanuma, 1993) by turning into single source suppliers of high value-added components. At the same time, they have a greater say regarding original equipment vis-à-vis the manufacturers while increasing their share in the spare parts market where the margins are higher (Jullien, 2002). But this strategy, espoused so enthusiastically by the FTSs, especially the European and American ones, is not without its risks:

- The FTSs shoulder a growing share of the industrial and financial risks while their access to capital does not match that of the automakers (Sako, 2003).

- The FTSs are required to widen considerably the range of their competencies which, in the context of a modularity-run, would lead to an external growth whose success is by no means guaranteed³.

In this way, F. Fourcade and C. Midler (2004) suggest that the existing technology/organisation couple does not ensure sufficient profitability for the parts manufacturers. According to these authors, modular organisation necessitates a radical transformation of technological modularity, which imposes a revolution in the way of thinking about innovation by the assemblers and in sharing the responsibility between car-makers and FTSs.

Even though further changes may well be expected on the part of the manufacturers in their role as architect, in the FTSs as suppliers of the modules and even in the coordinating methods between these two (Gerpisa, 2002), this does not take anything away from the fact that all the firms concerned are bent on adopting a modular architecture due to the fact that a very convenient division of labor has developed and that a modular product architecture opens new economic opportunities.

CONCLUSION

The automobile and aircraft industries have undergone a profound restructuring in the manner of designing their product and organising their supply chains. It would seem that a convergence appears in this search for modularity – in the sense that we define it – both technologically as well as organisationally. Within the domains analyzed, this convergence emerged via diametrically opposed paths⁴. The transition to modularity in the aircraft industry is primarily an adaptation of the organisational architecture to a pre-existing product architecture. In the case of the automobile, the modular architecture requires the development of new technological tools based on an organisation which is already modular at the global level.

These divergent trajectories bring into question some works on modularity which overdetermine the role of technology over organization. Even if we accept the hypothesis that

³ Between 1989 and July 2003, the 30 largest FTSs were involved in 957 take-overs (*Data Platinum*)

⁴ It would be wise to avoid presupposing that they would arrive at the same point or even anticipate the lines they would be likely follow as there appear a number of constraints from both the organizational as well as the technological viewpoints. We are referring especially to the transfer of risks towards the FTSs.

modularity is the objective of both these industries, we must assert that its adoption, in both the technological and organizational dimensions, is a result of:

- The past and present configurations of the two industries, especially the state of the structure (the kind of players, the power relationships) and the corporate strategy⁵.
- The diverse characteristics of the products (be it in terms of the number manufactured or the users).
- The rate of technological and organizational learning at the intra- and inter-firm level.

In this sense, this paper leads to the conclusion that the (technological) modularity does not automatically push to a kind of Legoland. More precisely, there is no technological determinism. The technical modularity and the organizational modularity are influenced by a lot of factors. And sometimes it is the technological modularity which pushes the organization. Sometimes it is the organizational modularity which induces to a transformation of the product architecture.

Our results are in accord with those of others who have pointed out that the individual trajectories of different corporations can also diverge in their turn (Freyssenet *et al.*, 1998). For example, even if all automakers adopt modularity, the organisational and technological strategies do differ, especially between the Japanese and Western manufacturers (Chanaron, 2001; Takeishi, Fujimoto, 2001). This difference modifies and at the same time, paradoxically, reinforces our stand. On one hand, it limits our study which is based on stylized facts, while on the other, it supports our cause by highlighting the fact that organisation is, to some extent, autonomous of technology. Whether we take a whole industry or any particular company, what matters is to comprehend at any given point in time the technology/organisation couple. The two can develop only subsequent to a technological as much as an organisational learning period, even if, as we have already seen, one of them (technology in aircraft and organisation in automobiles) can form the stimulus, probably only a temporary one, for the development of the pair.

REFERENCES

- AECMA, 2002: *Strategy paper for Regional Associations*, The European Association of Aerospace Industries, may 2002, Multig., 23 p.
- Amesse, F., Dragoste, L., Nollet, J. and Ponce, S. 2001: Issues on partnering: evidences from

⁵ See on this point Langlois (2004).

- subcontracting in aeronautics, *Technovation*, 21: 559-569.
- Asanuma, B. 1989: Interfirm Relationships in the Japanese Automobile Industry, *Revista Internazionale di Scienze Economiche e Commerciali*, 40(12): 1019-1040.
- Baldwin, C. and Clark, K. 2000: *Design Rules: The Power of Modularity*, Cambridge (Mass.): MIT Press.
- Bonaccorsi, A. and Giuri, P. 2001: The long-term evolution of vertically-related industries, *International Journal of Industrial Organization*, 19(7): 1053-1083.
- Boyer, R., Charron, E., Jürgens, U. and Tolliday, S. (eds.) 1998: *Between Imitation and Innovation. The Transfer and Hybridization of Productive Models in the International Automobile Industry*, Oxford: Oxford University Press.
- Brusoni, S. and Prencipe, A. 2001: Unpacking the Black Box of Modularity: Technologies, Products and Organizations, *Industrial and Corporate Change*, 10(1): 179-204.
- Brusoni, S., Prencipe, A. and Pavitt, K. 2001: Knowledge Specialisation, Organizational Coupling, and the Boundaries of the Firm: Why Do Firms Know More Than They Make?, *Administrative Science Quarterly*, 46(4): 597-621.
- Chanaron, J-J. 2001: Implementing technological and organizational innovations and management of core competencies: lessons from the automotive industry, *International Journal of Automotive Technology and Management*, 1(1): 128-144.
- Chanaron, J-J. and Lung, Y. 1995 : *Économie de l'automobile*, Paris : La Découverte.
- Clark, K. and Fujimoto, T. 1991: *Product development performance: strategy, organization and management in the world auto industry*, Boston: Harvard Business School Press.
- Erens, F. and Verhulst, K. 1997: Architectures for product families, *Computers in Industry*, 33: 165-178.
- Ernst, D. 2005: Limits to Modularity – Reflections on Recent Developments in Chip Design, *Industry and Innovation*, 12(3), this issue.
- Fourcade, F. and Midler, C. 2004: Modularisation in the auto industry: can manufacturer's architectural strategies meet supplier's sustainable profit trajectories?, *International Journal of Automotive Technology and Management*, 4(2/3): 240-260.
- Frenken, K. 2000: A complexity approach to innovation networks. The case of the aircraft industry (1909-1997), *Research Policy*, 29(2): 257-272.
- Freyssenet, M., Mair, A., Shimizu, K. and Volpato, G. (eds.) 1998: *One Best Way? Trajectories and Industrial Models of World's Automobile Producers*, Oxford: Oxford University Press.
- Frigant, V. 2005: Vanishing Hand versus Systems Integrators: Une revue de la littérature sur l'impact organisationnel de la modularité", *Revue d'économie industrielle*, Issue 109, 1^{er} Trimestre.
- Frigant, V. and Lung, Y. 2002: Geographical Proximity and Supplying Relationships in Modular Production, *International Journal of Urban and Regional Research*, 26(4): 742-755.
- Gadde, L-E. and Jellbo, O. 2002: System sourcing—opportunities and problems, *European Journal of Purchasing & Supply Management*, 8: 43-51.
- Galvin, P. and Morkel, A. 2001: The Effect of Product Modularity on Industry Structure: The Case of the World Bicycle Industry, *Industry and Innovation*, 8(1): 31-47.
- GERPISA, 2002: Verticals Relations and Modularisation in the Automotive Industry, *Actes du Gerpisa*, 33, http://www.gerpisa.univ-evry.fr/actes/actes_index.html.fr.
- Haas, J., Larre, F. and Ourtau, M. 2001: R&D dans le secteur aéronautique et spatial: tensions liées à un contexte nouveau", *Les notes du LIRHE*, 348.
- Hatchuel, A., Le Masson, P. and Weil, B. 2002: From knowledge management to design-oriented organizations, *International Social Science Journal*, 171: 25-37.

- Henderson, R. and Clark, K. 1990: Architectural Innovation: The Reconfiguration of Existing Product Technologies and the Failure of Established Firms, *Administrative Science Quarterly*, 35(1): 9-30.
- Jullien, B. 2002: Consumer vs. manufacturer or consumer vs. consumer? The implication of a usage analysis of automobile systems, *Competition and Change*, 6(1): 113-125.
- Kechidi, M. 1996: Coordination inter-entreprises et relations de sous-traitance: le cas d'Aérospatiale, *Revue d'économie régionale et urbaine*, 1: 99-120.
- Langlois, R.N. 2002: Modularity in technology and organization, *Journal of Economic Behavior and Organization*, 1(1): 19-37.
- Langlois, R.N. 2003: The Vanishing Hand: the Changing Dynamics of the Industrial Capitalism, *Industrial and Corporate Change*, 12(2): 651-385.
- Langlois, R.N. 2004: Competition through Institutional Form: the Case of Cluster Tool Standards, *Working Paper*, 2004-10, University of Connecticut, May.
- Langlois, R.N. and Robertson, P.L. 1992: Networks and Innovation in a Modular System: Lessons from the Microcomputer and Stereo Component Industries, *Research Policy*, 21(4): 297-313.
- Lung, Y. 2004: The Challenges of the European Automotive Industry at the Beginning of the 21st Century, *Working Paper of GRES*, 2004-08: <http://ideas.repec.org/s/grs/wpegrs.html>.
- Lung, Y. and Volpato, G. 2002: Redesigning the automakers-suppliers relationships in the automotive industry, *International Journal of Automotive Technology and Management*, 2(1): 3-9.
- McAlinden, S.P., Smith, B.C. and Swiecki, B.F. 1999: The Future of Modular Automotive Systems: Where are the Economic Efficiencies in the Modular Assembly Systems, *Michigan Automotive Partnership. Research Memorandum*, n°1, OSAT, University of Michigan, Transport Research Institute.
- Prencipe, A. 2003: Corporate Strategy and Systems Integration Capabilities, in A. Prencipe, A. Davies and M. Hobday (eds.), *The Business of Systems Integration*, Oxford: Oxford University Press: 114-132.
- Prencipe, A., Davies, A. and Hobday, M. (eds.) 2003: *The Business of Systems Integration*, Oxford: Oxford University Press.
- Sako, M. 2000: Modularity and Outsourcing: Main Issues and Trend, *IMVP Annual Sponsors Meeting*, MIT, Cambridge, Mass, 27-28 September.
- Sako, M. 2003: Modularity and Outsourcing: The Nature of Co-evolution of Product Architecture and Organisation Architecture in the Global Automotive Industry, in A. Prencipe, A. Davies and M. Hobday (eds.), *The Business of Systems Integration*, Oxford: Oxford University Press: 229-253.
- Salerno, M. 2001: The characteristics and the role of modularity in the automotive business, *International Journal of Automotive Technology and Management*, 1(1): 92-107.
- Salvador, F., Forza, C. and Rungtusanatham, M. 2002: Modularity, product variety, production volume and component sourcing: theorizing beyond generic prescriptions, *Journal of Operations Management*, 20(5): 549-575.
- Sanchez, R. 2000: Modular architectures, knowledge assets and organizational learning: new management processes for product creation, *International Journal Technology Management*, 19(6): 610-629.
- Sanchez, R. and Mahoney, J.T. 1996: Modularity, flexibility, and knowledge management in product and organization design, *Strategic Management Journal*, 17: 63-76.
- Schaefer, S. 1999: Product design partition with complementary components, *Journal of Economic Behavior and Organization*, 38: 311-30.

- Segrestin, B., Lefebvre, P. and Weil, B. 2002: The role of design regimes in the coordination of competencies and the conditions for inter-firm cooperation, *International Journal of Automotive Technology and Management*, 2(1): 63-83.
- Sturgeon, T. 2002: Modular production networks: a new American model of industrial organization, *Industrial and Corporate Change*, 11(3): 451-496.
- Sussman, S.W. and Guinan, P.J. 1999: Antidotes for high complexity and ambiguity in software development, *Information and Management*, 36(1): 23-35.
- Takeishi, A. and Fujimoto, T. 2001: Modularisation in the auto industry: interlinked multiple hierarchies of product, production and supplier systems, *International Journal of Automotive Technology and Management*, 1(4): 379-396.
- Talbot, D. 2000: Institutional dynamics on localised inter-firm: the case of Aerospatiale and the Toulousian subcontractors, *European Urban & Regional Studies*, 7(3): 223-236.
- Ulrich, K. 1995: The role of product architecture in the manufacturing firm, *Research Policy*, 24: 419-440.
- Veloso, F. and Fixson, S. 2001: Make-Buy Decision in the Auto Industry: New Perspectives on the Role of the Supplier as an Innovator, *Technological Forecasting and Social Change*, 67: 239-257.
- Volpato, G. 2004: The OEM-FTS relationship in automotive industry, *International Journal of Automotive Technology and Management*, 4(2/3): 166-197.