

## CORPORATE GOVERNANCE RELATIONSHIPS IN COMPLEX PRODUCT DEVELOPMENT: EVIDENCE FROM THE BUSINESS AVIATION INDUSTRY

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### Abstract

Corporate Governance relationships has become more relevant to the changed nature of the firm, the role of human capital has become very important in managing the firm in those environments where the source of competitive advantage is strongly based on knowledge and intangible resources as in the case of complex product systems industries. The important role of this intangible asset in managing the complex environment has amplified the incompleteness of the agency theory, changing the nature of the Corporate Governance relationships and highlighting the role of the human capital. This paper attempts to describe, using Problem Solving Behaviour approach, how the Corporate Governance relationships work in high competitive and complex environments as in case of the business aviation industry.

**Keywords:** corporate governance, aviation industry, product development

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### Introduction

Complex products systems (CoPS) are high value artefacts, systems, sub-systems, software packages, control units, networks and high technology constructs<sup>57</sup>. As high technology customised capital goods, they tend to be made in one-off projects or small-batches. The emphasis of production is on design, project management, systems engineering and systems integration. Examples include telecommunications exchanges, flight simulators, aircraft, aircraft engines, avionics systems, train engines, air traffic control units, systems for electricity grids, offshore oil equipment, baggage handling systems, R&D equipment, bio-informatics systems, intelligent buildings and cellular phone network equipment. They can be categorised according to sector (e.g. aerospace, military and transportation), function (e.g. control systems, communications and R&D), and degree of complexity (e.g. as measured by the number of tailored components and sub-systems, design options and amount of new knowledge required).

CoPS have at least three defining characteristics which distinguish them from mass produced goods. First, as high cost, capital goods they consist of many interconnected, often customised elements (including control units, sub-systems and components), usually organised in a hierarchical manner and tailored for specific customers and/or markets. Often their sub-

systems (e.g. the avionics systems for aircraft) are themselves complex, customised and high cost. Second, they tend to exhibit emergent properties during production, as unpredictable and unexpected events occur during design and systems engineering and integration (Boardman, 1990; Shenhar, 1994). Emerging properties also occur from generation to generation, as small changes in one part of a system's design often call for large alterations in other parts, requiring the addition of more sophisticated control systems and, sometimes, new materials (e.g. in jet engines). Third, because they are high value capital goods, CoPS tend to be produced in projects or in small batches which allow for a high degree of direct user involvement, enabling business users to engage directly into the innovation process, rather than through arms-length market transactions, as normally the case in commodity goods. There are many different dimensions of product complexity, each of which can confer task complexity and non-routine behaviour to production and innovation tasks. These dimensions include the numbers of components, the degree of customisation of both system and components, multiple design choices, elaborate systems architectures, breadth and depth of knowledge and skill required and the variety of materials and information inputs. Users frequently change their requirements during production, leading to unclear goals, uncertainty in production and unpredictable, unquantifiable risks. Managers and engineers often have to proceed from one production stage to the next with incomplete information, relying on inputs from other suppliers who may be competitors in other multi-firm projects. Many CoPS are produced within

<sup>57</sup> This section on CoPS definition draws from Hobday (1998).

projects which incorporate prime contractors, systems integrators, users, buyers, other suppliers, small and medium sized enterprises and sometimes government agencies and regulators. Often, these agents collaborate together, taking innovation (e.g. new design) decisions in advance of and during production, as in the case of flight simulators (Miller et al, 1995).

The dynamics of innovation and competition in CoPS industries differ from those in mass production (Bonaccorsi, et al., 1996; Davies, 1997; Hobday, 1998). CoPS require a wide breadth of knowledge and skills for their generation and development (Acha et al., 2004, 2007); “they are a function of the tacit processes of knowledge” (Paoli and Prencipe, 1999, p. 143). The civil aviation industry is characterized by complex knowledge bases and uncertainty in performance. Mowery and Rosenberg (1981) emphasized this point specifically: “Central to an understanding of the innovation process in the commercial aircraft industry is the high degree of systemic complexity embodied in the final product. The finished commercial aircraft comprises a wide range of components for propulsion, navigation, and so on, that are individually extremely complex. The interaction of these individually complex systems is crucial to the performance of an aircraft design, yet extremely difficult to predict from design and engineering data, even with presently available computer-aided design (CAD) techniques. (...) This pervasive technological uncertainty has been and remains an important influence upon producer structure and conduct in the industry.” (1981, p. 348). Eliasson (1996) discusses the same phenomenon which he terms ‘integrated production’ and draws particular attention to the capabilities of the systems integrator in this process. Complex technology may be more difficult to imitate. Most difficult to imitate, however, is the organizational capability to integrate complex technologies through product design, engineering and manufacturing processes, including designs that minimize future maintenance and modernization costs. Most of the knowledge is embodied in teams of people as “empirical experience” (Eliasson, 1996, p. 130). Prencipe categorizes the capabilities of firms developing multi-technology products. The taxonomy includes: 1) *absorptive capabilities* (abilities to monitor, identify and evaluate new opportunities emerging from general advances in science and technology); 2) *integrative capabilities* (abilities to set the requirements, specify source equipment, materials and components designed and produced internally or externally; and integrate them into the architectures of existing products); 3) *co-ordinative capabilities* (abilities to co-ordinate the development of new and emerging bodies of technological knowledge); 4) *generative capabilities* (abilities to innovate both at the component and architectural level) (Prencipe, 2001, p. 305–306). In other words, these firms should actually know a lot more than they do (Brusoni, Prencipe, 2001; Paoli and Prencipe, 1999). Others have found (Bonaccorsi and

Giuri, 2001) that the competitive factor in CoPS industries is the ability to manage simultaneously the task of systems integration and the pace of technological advancement. Therefore, the barriers to entry of producing CoPSs are very high and most, if not all, CoPS-producing industries tend toward oligopoly (Hardstone, 2004). Examples of CoPS industries tending toward oligopoly are the aero-engine industry (Phillips, 1971; Constant, 1980; Vincenti, 1986; Garvin, 1998; Bonaccorsi et al, 2005), the commercial aircraft industry (Acha et al., 2007; Phillips, 1971; Mowery and Rosenberg, 1981; Esposito, 1996; Vicari, 1989, 1991; Parazzini, 2003) and the business aviation industry (Mustilli and Izzo, 2008). It is clear that the academic studies have stressed the importance of knowledge about the nature of competition in CoPS industries.

Corporate Governance (CG) relationships<sup>58</sup> has become more relevant to the changed nature of the firm (Rajan and Zingales, 2000); the role of human capital has become very important in managing the firm in those environments where the source of competitive advantage is strongly based on knowledge and intangible resources (Nahapiet and Ghoshal, 1998) as in the case of CoPS industries. The important role of this intangible asset in managing the complex environment has amplified the incompleteness of the agency approach changing the nature of the CG relationships (Rajan and Zingales, 1998 and 2000) and highlighting the role of the human capital.

Our study attempts to describe, using Problem Solving<sup>59</sup> Behaviour (PSB) approach, how the CG relationships work in high competitive and complex environments as in the case of the business aviation industry. Business aviation refers to planes with fewer than 100 seats, owned by “a corporation or other business organization, powered by at least two engines, equipped to fly day and night and exists to transport business personnel, prospective customers, suppliers and friends in connection with the execution of business duties” (Jane’s 2005-2006, p. 18).

The paper is structured as follows. In the next sections we describe the basic principles underlying to PSB approach in firms, representing PSB as a form of complex design activity. The model – spelled out in more details in Marengo et al. (1999) and Dosi et al. (2000) – develops upon a ‘Simonian’ representation of

<sup>58</sup> CG relationships are viewed as a set of economic relations between the different stakeholders of the firm. The optimal set up of these relationships, toward common shared mission and vision and through governance mechanisms, gives rise to an efficient CG system oriented toward value creation for all the stakeholders.

<sup>59</sup> The term ‘problem-solving’ includes all the acts undertaken by individuals and groups within economic organisations (firms) to resolve organisational and technological problems and to conceptualise, design, test and build products and processes. The terms organisational form, structure and governance arrangements are used interchangeably in this paper.

PSB grounded on the notions of combination of elementary physical and cognitive acts, and decomposability of firm behaviour and structure in relation to particular product or process outcomes (Simon, 1981; 1991). We then describe the data, methodology and results. We conclude by discussing the article's contribution to the subject in hand.

## Theory

### Corporate governance and human resource

CG regulates the ownership and control of organizations (Berle and Means 1932). It sets the legal terms and conditions for the allocation of property rights among stakeholders, structuring their relationships and influencing their incentives, and hence, willingness to work together. Cooperation is important because of its role in making effective the diffusion of responsibility for production, process improvement and innovation. It also serves to secure the commitment of stakeholders to the objectives of the organization and to make available the full benefits of their skills, knowledge and experience. Ideally, this is a central purpose of Human Resource Management (HRM) and its role in enhancing organizational performance (Baker 1999; Black and Lynch 1997; Huselid 1995; Ichniowski *et al.* 1996; Konzelmann 2003; Pfeffer 1998). The form of Corporate Governance takes therefore impacts the effectiveness of HRM practices.

Advocates of HRM argue that it has become an increasingly important component of organizational strategy and that there is a growing recognition of the increasing returns to greater worker involvement in the planning and execution of work, as well as to worker self-regulation and a more democratic style of management (Appelbaum and Batt 1994; Blyton and Turnbull 1992; Guest 1987; Wilkinson 2003). Within the normative paradigm, the idea that an organization's human resources are of critical importance, and that the skills, knowledge and involvement of employees have strategic importance has led to the emergence of 'strategic' HRM (SHRM) (Dyer and Kochan 1995; Lundy 1994; Schuler *et al.* 1993; Truss and Grattan 1994). This strategic orientation has important implications for the interrelationship between HRM and governance. An important focus of SHRM is the notion of 'flexibility' and 'fit'. 'Flexibility' reflects an organization's capability of recognizing and adapting to changes in environmental pressures, opportunities and constraints (Snell *et al.* 1996). The concept of 'fit' rests on the idea that particular types of business strategy are best supported by specific 'bundles' of HRM practices and policies generating desired employee attitudes and behaviour (Capelli and Singh 1992). 'Fit' has both horizontal and vertical dimensions. Horizontal fit requires consistency within bundles of HRM practices (Baird and Meshoulam 1988), and vertical fit involves

aligning HRM practices with the firm's strategic business approach (Schuler and Jackson 1987).

The expectation of a direct link between an organization's strategic business approach and corporate governance opens up the possibility of a link between SHRM and the form taken by corporate governance. In discussing types of HRM practices, it is useful to distinguish between what have been described as 'hard' and 'soft' dimensions, both of which may be important in integrating HRM into business strategy but which differ in the contribution that employees are expected to make to the achievement of business objectives (Storey 2002). From the hard HRM perspective, labour is primarily a 'factor of production', the effective management of which requires emphasis on the 'quantitative, calculative and business strategic aspects of managing the headcount resource in as "rational" a way as for any other economic factor' (Storey 1987: 6). By contrast, *soft HRM* views workers as valued assets and 'a source of competitive advantage through their commitment, adaptability and high quality of skills performance' (Legge 1995: 66).

Yet regardless of the relative emphasis on hard and soft approaches, models of HRM assign central importance to *commitment* to the objectives of the organization (Guest 1987; Legge 1995; Walton 1985), where commitment implies 'identification with the goals and values of the organization, a desire to belong to the organization and a willingness to display effort on behalf of the organization' (Mowday *et al.* 1982). Organizational commitment is important because it is seen to motivate workers to work harder and go 'beyond contract'; to self-monitor and control, eliminating the need for supervisory and inspection personnel; to persist with the organization, thereby increasing the returns to investments in selection, training and development; and to avoid collective activities that might lower the quality and quantity of individual contributions to the organization (Guest, 1987).

Nevertheless, there are clear distinctions to be made between hard and soft HRM in management-worker relations. Hard HRM has a broader engineering base, a clear affinity with Taylor's vision of scientific management and thus requires more explicit top-down management. By contrast, soft HRM has firmer roots in human relations, requires greater involvement of workers, emphasizes voluntarism and democratic forms of government and depends therefore more on mutual trust than managerial authority for its successful implementation (see Appelbaum and Batt 1994, especially pp. 123–45). However, critics argue that soft HRM is a subtler version of hard HRM that essentially shares its aim of increasing management control and efficiency. They argue, further, that soft HRM is potentially more insidious than hard HRM because it tries to achieve control through colonizing employees' consciousness (Legge 1995; Willmott 1993).

## Problem-solving behaviour approach in firms

Before presenting the basic building blocks of PSB approach it is useful to briefly recall the governing principles behind the dominant agency approach. As known, agency theory identifies efficient incentive mechanisms for the co-ordination of decisions (see e.g. Tirole, 1986; Grossman and Hart, 1986; Laffont and Tirole, 1986), while implicitly assuming that PSB structures and search heuristics exist from the outset. Within firms, people are postulated to play extremely sophisticated games according to rules designed to prevent them from doing much harm to others. Neither the complexity of the task itself, nor the product of the firm or the production technology have much, or any, bearing on the subject at hand. The main aim is to generate admissible incentive-compatible procedures based on rational agents. Relatedly, individuals within organisations are assumed to hold the entire plan of what to do, possibly akin to a well-functioning computer model. The issue of firm competence and its relationship with performance does not arise, except for problems of the misrepresentation of 'intrinsic' individual abilities and adverse selection, or incentive misalignment in eliciting effort from individuals. Within the firm, as a first approximation, the social division of tasks is irrelevant to practice and performance. In the extreme, according to the mainstream approach, given the 'right' incentives, any firm can make any product as well as any other firm.

By contrast, at its most general level, the evolutionary approach sees economic organisations as problem-solving arrangements, viewing the different observed institutional set-ups in the real world as reflecting the complexity of the tasks and objectives faced by the firm (March and Simon, 1958; Nelson and Winter, 1982; Dosi and Marengo, 1994). In the world of complex and uncertain tasks, governance arrangements and search heuristics play a central part in determining which eventual solutions are considered as possibilities, tested and ultimately selected. Therefore the particular organisational arrangements and approaches, skill and experience in proceeding shape and define the distinctive competence of individual firms. As can be formally demonstrated, the design of suitable organisational arrangements tends to be even more computationally complex than finding an optimal solution to the problem itself (Marengo et al, 1999). To the extent that this is a correct representation of real world decision making, this implies that it is not sensible to assume that problem-solvers operate within *ex-ante* established organisational structures, governance arrangements and PSB routines. Indeed, organisational form has to be established as part of, and alongside, the problem-solving activity. Within this co-evolution of PSB and organisational arrangements, individuals, groups and entire firms are far from having perfect knowledge or foresight, but 'bounded rationality', broadly defined, is the rule (Simon, 1981; Dosi and

Egidi, 1991; Dosi, Marengo and Fagiolo, 1996). To resolve highly complex dynamic problems, boundedly rational individuals and groups within firms (as with the firm itself) are highly likely to adopt problem decomposition procedures, (for a thorough illustration, cf. among others, the example of aeronautical engineering in Vincenti, 1990). Here and throughout this work, largely in tune with Herbert Simon's perspective on problem-solving, by "decomposition" we mean the identification of ensembles of tasks or "sub-problems" whose solution is meant to yield also to the solution of the overall problem. So, for example, if the general problem is the development and construction of an airplane with certain technical characteristics, "decompositions" might involve the identification of "sub-problems" concerning e.g. engine thrust, wing loads, aerodynamic shapes of the body, etc. Over time, decomposition heuristics and routines are likely to evolve differently in different firms as they learn to reduce the dimensions of search space through experience. As a result, not all decomposition strategies are necessarily successful (or equally successful), and no selection mechanism or process of choice (e.g. incentives) necessarily exists to ensure an optimum solution to product, process or organisational problems.

In the evolutionary view (Simon, 1991; March and Simon, 1958; Radner, 1992; Nelson and Winter, 1982; Winter, 1982 and 1988; Dosi, 1988, Teece et al, 1994, Dosi and Marengo, 1994; Marengo, 1996) the basic units of analysis for PSBs are, on the one hand, elementary physical acts and elementary cognitive acts on the other. Problem-solving can then be defined as a combination of elementary acts within a procedure, leading eventually to a feasible outcome (e.g. an aircraft). PSB link with the notion of organisational competencies and capabilities. First, a firm displays the operational competencies associated with its actual problem-solving procedures (in line with the routines discussed by Nelson and Winter, 1982 and Cohen *et al.*, 1996). Second, the formal and informal organisational structure of the firm determines the way in which cognitive and physical acts are distributed and the decomposition rules which govern what is and what is not admissible within a particular firm (providing a route into the analysis of incentive structures and processes). Third, the organisation shapes the search heuristics for, as yet, unresolved problems, thereby governing creative processes within the firm. Fourth, PSB approach emphasises soft HRM, in fact the workers are valued a source of competitive advantage through their commitment, adaptability and high quality of skills performance.

## PSB approach in CoPS

The development of complex products poses substantial operational and organizational challenges to firms. In the operational (or product) domain, these challenges are met by breaking down complex

products into systems, which may be further decomposed into smaller components (e.g., Simon 1981, Suh, 2001). The product decomposition determines the architecture of the product, which is defined by the way components interface with each other so that the product can fulfill its functional requirements (Ulrich, 1995; Ulrich and Eppinger, 2004). In the organizational domain, firms meet the challenges of complex product development by assigning each component to a design team responsible for its design and for its integration with other components to ensure product functionality (e.g., Clark and Fujimoto, 1991). A complex product can be conceived as a network of components, with each component being a “node” and the interfaces between components being the “edges” (or ties) of the network. Similarly, the interactions among teams responsible for designing or for integrating such components can be viewed as a social network, with the teams being the nodes and the technical communication between them the edges of the network. Theoretically, an identified interface between two components should trigger some communication between the teams in charge of those components to address their technical interdependence. In some cases, however, communication between teams might also uncover previously unidentified interfaces between components. Yet, not all teams whose components are linked through an interface actually interact during the project implementation phase (Henderson and Clark 1990, Sosa et al. 2004), causing some interfaces to go unattended.

The interfaces among product components define technical interdependencies among teams, making effective collaboration across interdependent teams is one of the most critical challenges in complex product development (Thompson 1967, Galbraith 1973, Smith and Eppinger 1997, Mihm et al. 2003). Although, attention to technical interdependencies is crucial for successful product development, teams typically ignore (or pay marginal attention to) a number of interdependencies during the development process. Some level of neglect is perhaps unavoidable given the cognitive and resource limitations typically faced by teams (Simon, 1947, Ocasio, 1997). Lack of attention to non-critical or standardized interdependencies may not be ultimately significant (Sosa et al., 2004), but the neglect of critical interdependencies can have serious negative consequences for firms. For example, in a study of the semiconductor photolithography alignment equipment industry, Henderson and Clark (1990) found that novel interfaces between existing components were often neglected by design teams, causing established firms to lose their leading position in the market. In the auto industry, Ford and Firestone lost billions of dollars for poorly managing the interface between the tire design and the vehicle dynamics of the Ford Explorer (Pinedo et al. 2000). In the aerospace industry, Airbus’ development of its A380 plane has suffered significant delays due to the lack of attention

to some critical interfaces between the wiring systems and the fuselage (Gumbel, 2006, Hollinger and Wiesmann, 2006). The organizational literature inspired in social network theory has been mostly concerned with how communication networks can help or hinder an actor’s ability to collaborate with other interdependent entities. A substantial body of evidence suggests that this ability is enhanced by mutual trust and willingness to help others, which are associated with densely connected communication networks (Coleman, 1990).

Three mechanisms are commonly invoked to account for the positive effects of densely connected networks on product development efforts: information sharing, fostering of common culture and norms and reciprocity enforcement. First, when a focal actor is surrounded by a densely connected network, other actors in that network have both direct and indirect information on the motives and needs of the focal actor, removing barriers to knowledge sharing and facilitating collaboration in complex activities such as innovation (Ahuja 2000; Obstfeld 2005). Second, widespread interactions among members of the network may also facilitate the emergence of a common culture and norms that decreases the impact of competitive and motivational impediments to cooperation (Reagans and McEvily, 2003; Oh, Chung, and Labianca 2004). The benefits associated with densely connected communication networks should be apparent in the context of complex product development in two different ways. First, because dense networks facilitate information sharing, a focal team embedded in a densely connected communication network should find it easier exchanging information about all potential design issues that might affect its component. This, in turn, should make it easier to coordinate the component interfaces with other teams, reducing uncertainty and unexpected design interactions. Second, because densely connected networks enforce reciprocity, a focal team embedded in a dense communication network is more likely to receive help from other teams in that network. This mutual help creates flexible capacity within the group, which can free up resources in the focal team. Indeed, flexible capacity has been found an efficient way to reduce delays in the presence of workload variability (Adler et al 1995, Loch and Terwiesch 1999). Thus, the more a design team is embedded in a cohesive, densely connected communication network, the more it will enjoy the benefits of a collaborative environment, and the more likely it will be to attend to the critical technical interdependencies that result from the interfaces with other components in the product design process.

We attempt to describe, using PSB approach, how the CG relationships work in high competitive and complex environments as in case of the business aviation industry, in particular we study the relations across team network to the subject in hand. CG relationships are viewed as a *circulation of technology*

among teams; the meaning of “technology circulation” will be illustrated in the next paragraph.

## Methodology

In our study we adopted the survey instrument. It was the problem-focused, semi-structured interview. The use of semi-structured interviews allows for question adjustments during the interview, depending on the particular situation (Chirban, 1996). We interviewed with industry experts: marketing directors from the Italian Aerospace Research Centre, Piaggio Aero Industries and Alenia Industries, presidents from the Italian Business aviation Association and European Business aviation Association, and Dassault’s subcontractors (Dassault company is the big European manufacturer in the business aviation market). The questionnaire is divided in two parts: first, product network data and, second, communication network data. In the first part (product network data) we investigate following dimensions:

1. problem representations,
2. problem decompositions,
3. task assignments,
4. heuristics for and boundaries to exploration and learning

In the second part (communication network data) we study the interactions among teams during design of the project and production. In the aviation industry particular attention must be paid to the problem concerning the *circulation of technology* among teams. For this purpose the first step consists of defining the concept of a firm’s technology. It can be seen both as stock (an asset of the firm) and flow (a dynamic source in so far as it is continually supplied). As stock, the firm’s technology is incorporated in specific components, machinery, professional skills, information and organizational rules. The machinery category includes all technologies embodied in objects, components, parts, equipment and systems. The professional skills category includes all the person-embodied technologies, i.e. the whole set of human skills. In the information category there are the technologies embodied in the form of ideas and information recorded in manuals, articles, memoranda and any other written documentation. The organizational rules category includes all technologies embodied in the form of procedures and organizational linkages (The technology Atlas Team, 1987). As flow, it develops through the relationships with other firms, universities, and markets (Badaracco, 1991; Allen, 1988). From this point of view, the channels through which the firm communicates with the external environment are true vehicles of the circulation of technology. Technology as flow (in its capacity to transfer technology from and to the external environment) is transformed into technology as stock (and so into the firm’s technology). For example, the customer’s suggestions on quality control allow the supplier to acquire new procedures and organizational rules that enrich technology as

stock. Vice-versa, technology as stock turns into technology as flow (and influences the flow of technology to and from the external environment). Indeed, the capacity of the firm to operate with computerized systems allows interfacing with other firms through electronic channels and so provides a greater capacity to give and receive information. From this point of view, the problem of technology circulation between firms consists in the analysis of the channels through which technology as flow improves technology as stock. In the case of aviation industry eleven channels were identified (Esposito and Raffa, 1991; Esposito and Raffa, 1994):

1. raw material,
2. pre-finished parts,
3. specific processing equipment,
4. assistance to the supplier on specific issues,
5. integrator visits and suggestions,
6. collaboration at the beginning of the order,
7. written documents,
8. meetings held at the integrator site,
9. integrator visits to check the state of the order,
10. mixed work groups,
11. intervention by the integrator to improve quality control systems (QCS).

## Results and Discussion

The result of the interview showed that design of an aircraft requires the co-ordination of many different design elements. The interactions between the elements of the system can only be partly expressed by general models and have to be tested through simulation, prototype building, and trial and error moves where learning and tacit knowledge play an important part. Producing an effective solution, such as a new aircraft, involves a long sequence of moves, each of which is chosen out of an enormous set of possibilities. In turn, the relations among the moves in the sequence can only be partly known as a full understanding would (impossibly) require the knowledge of the entire set of possibilities.

The business aviation industry includes three sectors: airframe area, engines area and avionics-system area. The *airframe area* deals with company devoted to design and production of wings, fuselage, tail, nacelles and trust reversers, but few are also capable of dealing with the whole aircraft architecture and design, and the systems integration. The integrators are the main actors in this industry, their role, from a manufacturing point of view, may consist only of the assembly of various parts coming from subcontractor companies. The *engines area* includes companies that design and produce aeronautic engine of any type (turbojet, turboprop, propeller driven turboprop or pistons) and all necessary devices for interfacing the airframe and onboard systems. The *avionics area* deals with the design and production of all onboard efficiency and safety (flight instruments, navigation, communications, weapon systems). The *system area* refers to all remaining no electronic

system (such as landing gear, hydraulic system, electrical system and fuel system) that are on board of aircraft. Integrators, engines, and avionics/system areas tend a natural oligopoly because of the high level of technology and knowledge required. The main integrators in the business aviation industry are Cessna, Dassault, Gulfstream, Bombardier, Embraer. The engine manufacturers are Rolls Royce, Pratt & Whitney, Williams, Honeywell, General Electric. The avionics/system manufacturers are Honeywell, Collins and Garmin.

The CG relationships between integrator and engine manufacturer and between integrator and avionics/system manufacturer are quite easy to manager because of the high modularity<sup>60</sup> of the components. Modular components are less “connected” with other components and can be viewed as more flexible from a product design perspective because it has more degrees of freedom (Suh 2001). On the contrary, the CG relationships between integrator and its subcontractor companies are high interdependent because of the low modularity of the components. In fact, the results of interviews showed that the relationships between integrator and subcontractor are characterized by a high circulation of technology. These relationships are not only intense at the beginning of the order, as the written documents and the collaboration in the early stages of the order show, but they are also intense in the subsequent phases of the relationship, as meetings and visits to check the state of the order demonstrate. The integrator play an important role in the development of the technological system (visits and suggestions) and of the quality system (intervention to improve the quality control system) of their suppliers through technology circulation channels. The integrator not only ask their suppliers to produce one component or another according to their specifications, but also to participate in and carry on a complex network of relationships. This is why it seems essential that suppliers, along with technical skills, develop relational skills. Relational skill is the capacity of establishing close collaboration with the other firms and with the external environment in general. In the case of the suppliers, it is the skill of sustaining a complex network of relationships with the integrator and with the other suppliers.

<sup>60</sup> *Component modularity* is the main structural property that captures the lack of connectivity of a component with other components in the product. The common notion associated with modularity is that it decouples otherwise interdependent groups of elements. Decoupling of elements generates flexibility to adapt to changes. Modular products are easier to change and upgrade, facilitating product variety (Ulrich 1995). In the process domain, modular development processes are less prone to design iterations and rework (Smith and Eppinger 1997, Mihm et al. 2003). In addition, the work structure associated with modular components is less complex, which reduces the effects of ambiguity and uncertainty in development projects (e.g., Pich et al. 2002, Ethiraj and Levinthal 2004).

Traditionally, the supplier relationships in the aircraft industry formed a closed supply chain in the sense that the integrator attracted a network of sub-contractors. The same held true at the level of designing, where the integrator 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 integrator 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 integrator. 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. The importance, quantitative as well as qualitative, of the aircraft’s industrial components an integrator can no longer keep up with the entire set of systems due to the vast range of dissimilar skills that it now requires. At the same time, it must strive to refocus on its core skills and to limit itself to the role of designing and assembling the structural components. At the technological level, the centralisation of the competencies in the hands of the integrator has furthered the knowledge of the systemic complexity of the product and of the interfaces between the principal modules. 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. Moreover, 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: the mobilisation of the resources in the hands of the suppliers became the primary objective.

## Conclusion

The development of complex products poses substantial operational and organizational challenges to established firms. What one could call the “problem-free” assumption is profoundly unrealistic, this is especially important where tasks are inherently complex and non-routine in nature and where many possible problem-solving and organisational solutions are possible. We adopted PSB approach to understand the problem of CG relationship in the business aviation industry. CG relationships are viewed as a circulation of technology among teams. The study showed that the basic principles on which the whole philosophy of CG relationship across interdependent teams are “integration” and “coordination”. CG relationship have progressed from an intra-firm to an

inter-firm orientation. Relationships have gained in importance as a source of competitive advantage, they are characterized by a wide collaboration based on mutual trust and on intense technology circulation.

### Future Work

The research raises a number of other interesting questions that can stimulate future research on the topic: how does the communication network structure of teams mitigate design interactions (or design oscillations)? How does component modularity and team network structure relate to important design decision such as outsourcing or off-shoring? Why are some teams better than others attending to their critical technical interdependencies? Is it because of some attributes of the components they design, or because of their communication patterns with other teams in the organization, or both?

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