Abstract
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and pitfalls of outsourcing and early supplier integration, less attention has been paid to how to sequence these two changes. Drawing on a case study of Airbus’ Equipment and Systems domain that recently fostered its role as a systems integrator, we study two aircraft systems that differed in their changes along the two dimensions. Our case allows us to disentangle the resulting challenges and to cast light on the question how to choose between different transformational paths to becoming a systems integrator. The case documents the challenges that the transformation involves and how they materialized in the context of the two systems. Two aspects characterized the adaptive response of the organization: a highly differential treatment of various systems and subsystems, and pushing the envelope very carefully while making provision and time for experiential learning by the suppliers and the OEM alike.
Choosing Paths to Becoming a Systems Integrator: 
Lessons from Airbus’ “New Systems Policy”

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Keywords: Complex product systems, systems integration, outsourcing, buyer-supplier relations, aircraft manufacturing, innovation management
The last years have seen a remarkable increase in the division of R&D labor among firms. Within the management and organization literature, choices between market-based, hierarchical, or hybrid solutions to organizing economic activity have a long-standing presence (Barney 1991; Williamson 1991; 1999). Spurred by the increasing prevalence of outsourcing knowledge-intensive work, research in the past decades has started to focus on the field of outsourcing R&D specifically and to take a more fine-grained perspective. In particular, it has focused on the underlying architecture of product systems and on the roles of component-level vs. system-level knowledge as important contingency factors of successful R&D practices (Henderson and Clark 1990; Brusoni et al. 2001; Cabigiosu and Camuffo 2011). One stream of work has focused specifically on complex product systems that consist of many interdependent subsystems and that involve numerous technologies (Davies 1997; Davies and Brady 2000). Scholars in this tradition have pointed to the capabilities that outsourcing firms need to retain to be able to integrate the various (sub)systems, and that may put limits to the division of R&D labor (Hobday et al. 2005; Zirpoli and Becker 2011).

The common theme of these approaches is that outsourcing R&D involves balancing numerous benefits and challenges: One the one hand, outsourcing may have beneficial effects on the efficiency of the R&D activities and allow a firm to focus on a (more profitable) role as an integrator, rather than a producer, of complex systems. On the other hand, it often requires fundamental organizational changes, involves additional coordination and cooperation challenges, and entails the risk of lacking or losing critical capabilities (Prencipe 2000; Brusoni et al. 2001; Zirpoli and Becker 2011). Extant research has suggested various criteria that firms need to pay attention to when deciding about the division of R&D labor (Brusoni et al. 2001; Chesbrough and Kusunoki 2001; Parmigiani and Mitchell 2009). Moreover, as issues of R&D outsourcing can obviously not be reduced to binary decisions between in-house “make” and market-based “buy” (or some intermediate solution), the organizational challenges firms are facing are more complex. In consequence, a different line of research has pointed to different forms of involving suppliers at various stages of the R&D process and has suggested criteria for organizing buyer-supplier relationships accordingly (Dyer and Singh 1998; Sobrero and Roberts 2001; Dyer and Nobeoka 2002).
Although extant work thus paints a rather clear picture of the requirements and pitfalls of R&D outsourcing in complex systems, fairly little research exists on which paths firms (should) take if they want to transform themselves from integrated producers of complex systems into systems integrators. Specifically, we argue, the literature is rather silent as to the role played by two fundamental, interdependent dimensions that this transformation necessarily involves: (1) increasing the level of outsourcing by shifting larger packages to suppliers, and (2) involving the suppliers earlier in the systems development process. Do the challenges that firms face differ in their kind, multitude, or strength, depending on which dimension firms change first? Put differently, should firms first involve their suppliers in early development phases, and then outsource further activities to the suppliers? Or should they first shift larger packages to their suppliers, and only later integrate the suppliers in early phases? Or is the magnitude of the change, rather than how it is sequenced, of larger importance?

While both dimensions are obviously interdependent, we argue that firms still have some latitude for shaping them differentially. To identify the challenges that the transformation from integrated producer to systems integrator entails, and to better understand the different transformational paths to becoming a systems integrator and relevant considerations for choosing one path, this paper uses a case study of the aircraft manufacturer Airbus. With the launch of its A350 aircraft program in 2006, the firm implemented a “New Systems Policy” in its Equipment & Systems area and shifted responsibility for entire (sub)systems to its suppliers. We specifically study two aircraft systems that have been subjected to similar changes in the supplier relationships, but to different degrees of change along the outsourcing dimension. Comparing the two systems allowed disentangling, to some extent, the effects of increasing the level of outsourcing and of involving suppliers earlier in the development process. The case documents the challenges involved in becoming a systems integrator, and how two different departments in Airbus have addressed these challenges. The complexity of the problem precluded any up-front

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1 Extant work on systems integration and on integrated solutions and services (e.g., Kaufman et al. 1996; Brusoni et al. 2001; Galbraith 2002; Davies 2004; Hobday et al. 2005) has largely focused on the basic strategies underlying these approaches, on the evolution of (originally) smaller firms, or on organizational responses to technological change. In-depth empirical accounts of specific transformational paths of producers of complex product systems that intend to focus on their role as systems integrators, in contrast, appears to be less developed.
definition of comprehensive solutions. Instead, two aspects characterized the adaptive response of the organization: a highly differential treatment of various systems and subsystems, and pushing the envelope very carefully while making provision and time for experiential learning by both suppliers and the OEM alike.

The remainder of this article proceeds as follows. The next section outlines our conceptual understanding of the changes that a transformation from producer to systems integrator entails, and reviews prior work that speaks to the expected challenges. Sections three to five contain our case study. The final section summarizes our findings and discusses how they contribute to the existing literature.

PATHS TO BECOMING A SYSTEMS INTEGRATOR

Conceptual Representation

To think about the transformation of an integrated producer of complex systems into a systems integrator, it is helpful to start from the process along which complex product systems such as aircraft are developed. Most commercial and defense-related systems engineering projects follow some variant of the so-called V-Model that structures the systems development process along the two limbs of a V (Forsberg et al. 2005). Figure 1 depicts a generic V-Model with an exemplary application to aircraft systems. The left limb of the V represents the design and specification phase, whereas the right one denotes the integration and testing phase (Alexander and Maiden 2004), with time flowing from left to right. At the start of a development project at the upper end of the left limb, the final product is conceptualized according to customer needs and strategic market aspects, and top-level requirements are defined. As the development moves down the left limb, the specifications become more detailed. First, systems and interactions between systems are functionally specified, followed by specifications on the subsystem and component levels that describe the architecture and requirements of these elements. Finally, at the lower

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2 The process model that Figure 1 represents is the simplest, and most static, version of the V-Model. More specific instances of the model typically allow also for iterations across certain stages, they include validation and verification activities across stages and limbs, and identify critical milestones along the process. Within Airbus, this process is known as “Requirement-based Engineering.”
end of the left limb, the materials for single components and modules are chosen. With the entire product being fully specified at this point, the actual implementation of the components, subsystems, and systems begins. While moving up the right limb of the V, first the lowest-level components, then subsystems and, finally, systems, and groups of systems are integrated and tested. Finally, once all systems are assembled, the entire product is tested again.

< Insert Figure 1 about here >

The V-Model points to an intuitive refinement of the extant conceptualization of systems integrator firms as being concerned with concept design and integration tasks, while outsourcing detailed design and manufacturing (Brusoni et al. 2001). In particular, it suggests that outsourcing and systems integration may occur at different levels in the systems development process, which can be represented by a horizontal line in the V-Model that denotes the transition between the R&D activities of the buyer and those of the supplier. For instance, a very low horizontal line would indicate that an OEM specifies a system all the way to the level of individual components, outsourcing only the detailed development and implementation of the components to its suppliers, and eventually integrating the components into larger aggregates.3 On the other hand, an OEM might also specify a system down to the subsystem level only, assigning responsibility for detailed subsystem design, testing, and manufacturing to its suppliers, and eventually integrating the final system from externally-sourced subsystems. Lastly, the OEM might also engage only in describing high-level functional requirements and grant its suppliers responsibility for the design and production of entire systems, or sets of systems.

< Insert Figure 2 about here >

Figure 2 summarizes our arguments. Integrated producers of complex systems that want to focus on their integrator role will “move” the horizontal line that separates their domain from those of the suppliers further “up the V.” This movement, we posit, entails changes along two fundamental

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3 What denotes a single “component” for an aircraft manufacturer (e.g., a control computer), might denote an entire “system” for the supplier of this component.
dimensions. We dub the first one the “scope of outsourcing” dimension, as suppliers become responsible for larger packages (e.g., an entire system instead of only single components); these larger packages are also increasingly complex. Moreover, the complexity of the supply chain is rising as well, because the supplier will likely require sub-suppliers and partners itself. Second, and related to the former issue, “moving up the V” requires the systems integrator to involve suppliers in earlier phases of the systems development process, i.e., when the overall system is not entirely specified yet, when design efforts proceed concurrently, and iterations proliferate. Hence, the earlier suppliers are integrated, the more uncertain the situation that the OEM and its suppliers need to resolve, and the more “Black Boxing” their relationship will entail. To further describe the two dimensions, our review below draws from two streams of research: (1) studies on complex product systems that have discussed outsourcing and the role of systems integrators, and (2) research on integrating suppliers (early) in complex systems R&D. In doing so, we focus on the conditions and potential challenges that prior research has attributed to these concepts.

**Outsourcing Complex Systems Development**

What conditions facilitate outsourcing in complex systems development? Various studies have probed the “mirroring hypothesis,” i.e., the idea “that in the design of a complex system, the technical architecture, division of labor and division of knowledge will “mirror” one another in the sense that the network structure of one corresponds to the structure of the others” (Sanchez and Mahoney 1996; Baldwin and Clark 2000; Sosa et al. 2004; MacCormack et al. 2006; Colfer and Baldwin 2010, p. 7). For instance, Sanchez and Mahoney (1996) propose that to develop an integral product, managerial authority is necessary for coordination, while modular products are likely to be developed in a modular organizational setting which does not require coordination become modules are independent. Similarly, Chesbrough and Kusunoki (2001) suggest that technologies in a “modular” stage should be developed in a decentralized organization whereas centralized organizations are better suited for “integral” technologies. If a firm attempts to develop an integral technology in a decentralized manner, it runs the
risk of ending in a “modularity trap.” Dealing with a technology with unpredictable interactions, the integrating firm will be unable to specify the requirements to its suppliers.

Despite its intuitive appeal, however, the applicability of the mirroring hypothesis is limited (Colfer 2007; Cabigiosu and Camuffo 2011). One reason is that when dealing with complex products systems, a clear distinction between modularity and non-modularity is rarely possible. The product architectures of cars, for instance, are characterized by “persistent integrality” (MacDuffie 2008). Another reason is that even though product modularity facilitates outsourcing, the “mirror can be broken,” allowing for outsourcing even if the respective part is not (fully) modular (e.g. Clark 1989; Argyres 1999; Helper et al. 2000; Takeishi 2001). To break the mirror, however, certain organizational requirements must be met. According to Brusoni and Prencipe (2001), systems integrators require architectural knowledge (Henderson and Clark 1990) that enables them to integrate components into well-functioning systems. Likewise, component-specific knowledge can also be decisive for OEMs to coordinate the decentralized learning trajectories of their specialized suppliers (Prencipe et al. 2003). While component-specific knowledge can best be learned by doing (Zirpoli and Becker 2011), a different approach is to establish close relationships with the suppliers – a notion that is well in line with research suggesting that modularity in product design increases the need for “thick” supplier relationships (Hsuan 1999; Hoetker et al. 2007; Parmigiani and Mitchell 2009; Cabigiosu and Camuffo 2011). Argyres and Bigelow (2010) point to another potential downside of outsourcing. In a study on the early automotive industry in the United States, they find evidence that differentiation becomes more difficult, as firms lose direct influence over critical variables. In a similar manner, Zirpoli and Becker (2011) further elaborate on the limits of outsourcing by pointing to the risk of outsourcing component technologies that “(1) have a direct impact on key product performances and (2) present a high degree of reciprocal interdependences with the key technologies contributing to the overall product performances” (Zirpoli and Becker 2011, p. 36).

Increasing the level of outsourcing also relates to the suppliers that need to develop more complex systems than before, and several studies point to the risks and challenges involved in this transformation process (Sawhney et al. 2004; Ro et al. 2007). Consider, for instance, the automotive
industry, where 1st tier suppliers have often resumed responsibility for the design and integration of complete systems (Fixson et al. 2005; Doran et al. 2007). In doing so, suppliers not only increase the scope and sophistication of their products, but likewise of their supply chain activities as they must learn to interact with both the OEM and a large number of 2nd and 3rd tier suppliers in order to provide an integrated system (Ro et al. 2007). In addition to the challenges of managing the supply chain, one fundamental challenge stems from the fact that when a component maker controls only a subset of an overall system (say, an electro-magnetic sensor for a control system), the firm is only concerned with the performance of this subsystem.\footnote{With the term “system” (“subsystem”), we denote the entirety (or subset, respectively) of activities and decisions necessary to design, manufacture and market a complex product system.} Although it needs to take into account how the other components affect the optimal design of its own component – for instance by accounting for standards or specified interfaces – these other subsystems are out of its reach and therefore must be taken as given. Likewise, the component maker will not consider whether changes to its own component might affect the value of the components that are not under its control (such as, for instance, the software to network the sensors). If, however, the firm is to supply an entire system, the firm has to be concerned with the overall system performance and needs to understand and consider system-level interdependencies, i.e., how changes in one component affect the values of any of the other subsystems, and thus to balance a higher number of interdependent system elements. Furthermore, gaining control over all components of a system not only increases the scope of performance contributions that the firm must consider simultaneously, but likewise increases its range of options for making changes to these different components.

As a result of these issues, the cases of component makers transforming into system suppliers that are featured in the literature bear witness of rather lengthy processes required to build up the necessary capabilities (Jung 2005; Ro et al. 2007). For example, the German Robert Bosch AG evolved from a small workshop into an international “0.5 tier” supplier over a range of several decades (Kash and Auger 2005). Studying the case of the Hadco Corporation, Kaufman et al. (1996) and Wood et al. (1996) likewise show that it took the firm a significant amount of time and effort to master the transformation
from a product specialist to a problem-solving supplier. Similar claims are made by Davies (2004) and Davies et al. (2006) for the cases of Alstom Transportation, Ericsson, and other producers of complex product systems.

Involving Suppliers under Uncertainty

Extant research has discussed various concepts of involving suppliers in the R&D process, most of which are based on Clark and Fujimoto’s (1991) classification of supplier-proprietary parts, detail-controlled parts, and black box parts. Supplier-proprietary parts characterize off-the-shelf products with standard interfaces that are entirely designed and manufactured by a supplier and then sold without almost any deeper interaction. For detail-controlled parts, on the other hand, a supplier is usually given detailed specifications by the OEM, i.e., only the manufacturing and (perhaps) the assembly of the components is essentially outsourced. Such “white box” supplier relationships (Monczka et al. 2000), “low design responsibility scenarios” (Jung 2005), or “collaborative development projects” (Le Dain et al. 2011) leave little responsibility with the supplier and are often applied in projects that involve mature technologies, i.e., when the supplier’s specific knowledge is not important to the buyer. Moreover, the relationships between buyers and suppliers need not be very close, because interfaces are typically already clearly defined.

In case of black box parts, the OEM benefits from the knowledge of a supplier by transferring a significant part of the design work to it. As the supplier is supposed to contribute to the product with its knowledge (Handfield et al. 1999; Sobrero and Roberts 2001), the buyer-supplier collaboration is intense and typically starts early in the development process. In black box engineering, the division of responsibility in the development process is the key distinguishing feature, with the supplier participating actively in the design work according to functional specifications by the buyer (Le Dain et al. 2011). Given such higher-level specifications, the supplier is not only responsible for the production and assembly processes, but also for concept and feasibility studies, the actual design process, as well as testing activities (Wynstra and Pierick 2000). Black box engineering thus constitutes a particular
challenge for suppliers, because they have to collaborate with the buyer in specifying the parts instead of working according to specifications that are provided by their customers. This requires a highly interactive design process, with (changing) specifications becoming an open medium for communication and learning (Karlsson et al. 1998).

As producers of complex systems outsource R&D and assume the role of systems integrators, supplier relationships can be expected to change from white box to black box. This change implies an earlier involvement of suppliers and a shift of specification tasks and responsibilities to suppliers. Moreover, the most fundamental aspect of early supplier involvement, and the underlying driver of the above challenges, is the fact that collaboration in early phases of the systems development process occurs in a situation of high uncertainty (Bozdogan et al. 1998; Mikkola and Skjoett-Larsen 2003). As the functional requirements and the architectures of the system are only about to evolve, both buyers and suppliers need to adapt to a high likelihood of (dysfunctional) problem-solving oscillations (Mihm et al. 2003) or, at least, multiple (valuable) iterative rounds of design and experimentation (Thomke 2003). In sum, thus, even though a larger responsibility is shifted from a buyer to its suppliers, the uncertainty that surrounds the early involvement of suppliers will in fact entail a higher, rather than a lower, degree of buyer-supplier interdependence. Rising interdependence between buyers and suppliers, in turn, mandate higher levels of information sharing and knowledge exchange to coordinate the joint problem-solving processes. To address these challenges, firms need to adopt practices of concurrent engineering (Loch and Terwiesch 1998) and develop routines for dealing with issues of technical content and the level of detail of requirements, adjusting specifications, and communicating effectively.

METHOD

Basic Considerations

To illustrate and refine our conceptual arguments, we use a single case study (Yin 2003; Eisenhardt and Graebner 2007; Siggelkow 2007). Single cases are well suited for our purposes, as they
allow a rich description of complex organizational processes and relations and thus can help generate broader theoretical insight (Weick 2007). Studying the challenges that arise in the transition to systems integrator required a research setting that allowed insight into the processes of complex systems development, as well as sourcing patterns that are changing towards higher-level outsourcing. Airbus – one of the two market leaders in the aircraft industry – possessed these features which made it suitable for our purposes. First, aircraft are obviously highly complex product systems that are developed following a traditional development process that progresses along a (firm-specific) V-Model. Second, with the exception of suppliers engaging in component-specific R&D activities, R&D outsourcing does not have a long-standing tradition in this industry. Third, over the past few years, and driven by a strategic decision, Airbus has significantly increased its level of outsourcing. The fact that this change occurred rather recently allowed our interviewees to comment on its implications from personal experience; the fact that it occurred rather swiftly made the challenges it yielded more directly observable.

More broadly, our case also allows us to gain industry-specific insight into organizational changes in the civil aircraft industry. Most extant research on changing supply patterns, in contrast, has focused on the automotive industry. This industry has often demonstrated to be more innovative than firms in other industrial sectors in adopting new organizational and management practices such as lean manufacturing, total quality management, or higher-level outsourcing sooner. (Nonetheless, the successful adoption and adaptation of lean manufacturing concepts took the industry many years, if not decades.) Due to its specific characteristics (e.g., very long development and product life cycles, very high product complexity, very high capital intensity), the civil aircraft industry has traditionally been rather slow in adopting new organizational and management practices. Higher-level outsourcing thus denotes a relatively new phenomenon that will affect future industry structures in fundamental and significant ways. Adding to extant research on outsourcing and systems integration in the aircraft industry that has dealt with supply structures for (components of) the propulsion system (Brusoni et al. 2001;  

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5 An exception is the context of propulsion systems, i.e., aircraft engines. Here, aircraft manufacturers have traditionally been dependent on suppliers such as GE, Rolls Royce, or MTU.
Prencipe et al. 2003), our study is concerned with other aircraft systems, for which the OEM’s “make” share has traditionally been larger.

**Specific Context**

We specifically studied Airbus’ Equipment & Systems (E&S) domain, which is responsible for many critical systems such as air systems, auxiliary power units (APU), avionic systems, flight control systems, or the landing gear structures. We chose this focus for two reasons. First, with the start of the A350 program in 2006, Airbus introduced a “New Systems Policy” (NSP) in the E&S domain – a restructuring strategy to benefit from higher levels of outsourcing. While Airbus had already subcontracted the design of various components to specialized suppliers, the NSP was summarized by “wider and earlier”, which implied (1) subcontracting more comprehensive and integrated packages to suppliers and (2) involving and selecting suppliers earlier in the development process. Second, for various reasons, the level of R&D outsourcing varies across different systems in the E&S domain. Moreover, the processes of transforming from “make” to “buy” across different systems of the E&S domain can be compared more easily than changes that have occurred in, for instance, the aerostructures domain. In our analysis, we focused on the implications of the NSP for two specific (groups of) systems: the Environmental Control System (ECS) and the High-Lift System. In the case of the former system, suppliers were given significant responsibility, even for entire groups of interconnected systems. In the case of the latter system, in contrast, only components or, at the most, subsystems have been outsourced to suppliers.

In sum, thus, our analysis is based on two systems within Airbus’ E&S domain. Starting from established structures of organizing buyer-supplier relationships, both systems were simultaneously subjected to Airbus’ New Systems Policy of lowering the company’s “make” share. But while the changes that were induced by the NSP lead to an early supplier involvement that affected both systems, the level of outsourcing, or the size of the packages that were allocated to suppliers, differed significantly across the two systems. Hence, as we argue below, the two systems we chose have been exposed to
similar changes along the uncertainty dimension, but to a different degree of change along the complexity dimension. Comparing the two systems thus allowed disentangling, to some extent, the two interrelated effects of higher-level outsourcing.

**Data Collection and Analysis**

The data for our case study were obtained from several primary and secondary sources. Primary sources included in-depth, semi-structured interviews as well as corporate reports, policies, and presentations. After identifying, through several exploratory talks with Airbus managers from strategy, engineering, and project management, examples for aircraft systems with differing levels of outsourcing in the development process, we arranged interviews with engineers, procurement managers as well as suppliers of the corresponding functional units. In sum, we conducted 18 interviews in 2011 and 2012 with Airbus representatives from Germany and France, ranging from 40 min to several hours. Interviewees included engineers that are managing different departments in the area of the Environmental Control System (e.g., the air conditioning) and the High-Lift System. We also interviewed several senior managers such as current and past program heads as well as executives for procurement, including the procurement strategists responsible for the strategy of increasing the level of outsourcing. Furthermore, interviews were undertaken with suppliers for several aircraft systems as well as with external industry experts, whose external, complementary views were used to validate our interpretations of the data collected within Airbus. All interviews were transcribed, analyzed, and contrasted to the literature, thus informing, in an iterative manner (Miles and Huberman 1984), the ongoing data collection process. Secondary sources that we used to further cross-check our analyses included press articles and company reports that we derived from a systematic web search (e.g., in industry databases such as Flightglobal or Airframer, or discussion boards dealing with the aerospace industry or aircraft design and development).
SOURCING IN THE AIRCRAFT INDUSTRY

Industry Structure

The civil aircraft industry is an oligopoly with two major aircraft manufacturers, Airbus S. A. S. – a subsidiary of the European Aeronautic Defense and Space Company (EADS) – and the Boeing Company. Both companies offer a wide spectrum of aircraft families, ranging from short-range (Airbus A320 family and Boeing 737) to long-range aircraft (Airbus A330/340, A350 XWB and Boeing 767, 777, and 787). Even though the industry is characterized by high entry barriers (Wang et al. 2005) due to its capital intensity and demand for highly skilled labor, competition from smaller companies such as Comac (Commercial Aircraft Corporation of China), Bombardier (Canada), or Embraer (Brazil) is increasing. Aircraft are characterized by long development cycles and manufacturing lead times (5 to 10 years) as well as very long product life cycles of up to 40 years. Moreover, while civil aircraft is considered a high-tech industry, strict safety regulations imply that only well-established and proven technologies are used. For this reason, every detail of the aircraft development process is strictly monitored, and aircraft must be certified by the aviation authorities. Even though the industry is thus considered conservative (Rose-Anderssen et al. 2010), almost all recent aircraft families (e.g., the Airbus A380 or A350 XWB) comprise several entirely new technologies or materials.

In the past, aircraft manufacturers developed only one aircraft family at a time. Today’s competition, however, forces them to respond to differentiated market needs and develop multiple aircraft programs in parallel. During its first 20 years of operations, for example, Airbus had launched the first four aircraft families successively (the medium-range A300, the long-range A310, the short-range A320 for short range, and the long-range A330/340). Since the year 2000, however, three entirely new aircraft families – the A380 super jumbo, the A400M military transport aircraft, and the A350 XWB (extra wide-body) airliner – have been initiated within 10 years. (Very recently, the firm also announced another new program – the new generation of the A320 family.) At the same time, the complexity of modern aircraft continues to rise due to aircraft systems becoming increasingly software-intensive, the number of
interfaces rising, customers asking for extensive customization options, and tight safety regulations (Altfeld 2010).

**Changing Patterns**

Because no firm can develop and manufacture multiple aircraft families on its own, aircraft OEMs rely on a wide network of suppliers and sub-suppliers (Rose-Anderssen et al. 2011). Whereas material and make-to-print parts have been sourced from suppliers for many years, OEMs recently started to outsource also design and integration work to subcontractors. Hence, with OEMs focusing on their role as architects and systems integrators, the aerospace industry is following a trend that originated in the automotive industry fifteen years ago. Consequently, both Boeing and Airbus redesigned their supply chains during their last development programs, especially for their latest long-range wide-body programs, the Airbus A350 XWB and the Boeing 787, respectively. While OEMs had been used to assembling parts from a large number of suppliers, they now strive for a small number of first-tier suppliers to integrate subsystems and systems delivered from lower-tier subcontractors, focusing themselves on the final integration of systems in the airplane. Boeing, for instance, reduced a four-digit number of suppliers to approximately 50 first-tier strategic partners, while increasing the share of outsourcing from 35 to 50% in the 737 program, to 70% outsourcing in the 787 program (Tang et al. 2009).

< Insert Figure 3 about here >

Airbus followed a similar but more conservative approach to outsourcing than Boeing. (The evolution of Airbus’ “make” share is depicted in Figure 3.) When launching the A350 XWB program in 2006, Airbus issued a general make-or-buy policy (“focus on core”): “Keep in-house work that (1) is key for architecture and integration, (2) is a complex area of integration, (3) relates to product safety, (4) is important for technology leadership, [and] (5) is key for differentiation.” Overall, these changes were initiated to reduce development lead time and resource requirements through an earlier and more collaborative approach to working with suppliers. Furthermore, Airbus intended to secure technology
leadership while increasing supplier involvement and fostering “one stop shopping” for customer support. Resulting from this policy, according to one interviewee, Airbus now aims at “mak[ing] the upper part of the V,” i.e., to engage in the general definition of a system’s architecture and its functional specifications, while outsourcing downstream R&D activities, before integrating the final system. For its A350 program, for instance, Airbus relies on 53 first-tier suppliers. Moreover, Airbus’ general approach to anchoring the new sourcing policy throughout the organization, however, is implemented differently across the firm’s five engineering and purchasing domains (Propulsion Systems, Cabin, Material and General Procurement, Equipment & Systems, and Aerostructures). Due to differences that result from the different (historic and technological) contexts of the five domains, the horizontal line that cuts the “V” is thus also different in the different areas. As discussed in §3, the following analysis focuses only on the E&S domain.

EFFECTS OF THE NEW SYSTEMS POLICY

As intended by its aim of “wider and earlier,” the NSP led to (1) an earlier supplier involvement and (2) to a larger share of development activities being outsourced to suppliers. As the former change affected the firm’s supplier relationships across all systems in the E&S domain in a very similar manner, we first describe these respective changes in general. Subsequently, we outline how the level of outsourcing was adjusted (differently) in the two systems in our sample, the Environmental Control System (ECS) and the High-Lift System.

Earlier Supplier Involvement

Before the introduction of the NSP, suppliers essentially became active between the end of the concept phase and the freeze of definitions, i.e., when aircraft structures and configurations were predominantly stable. Today, a shortlist of suppliers (engaging in joint work with Airbus without any contracts) exists from the beginning of the concept phase. Subsequently, using a selection process that has been significantly shortened, one supplier is chosen in the middle of the concept phase, i.e., at a time

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6 In addition to the scope of outsourced activities becoming larger, the size of the outsourced packages increased significantly as well, as the number of outsourced work packages in the E&S domain decreased by more than 40%.
when the overall aircraft concept has not been “frozen” yet. Put differently, suppliers now enter the development process at a time when no detailed definition of a system (or the entire aircraft, for that matter) exists. Figure 4 illustrates these changes.

< Insert Figure 4 about here >

**Increasing the Scope of Outsourcing: The Environmental Control System**

*Technical characteristics.* Civil aircraft often fly in altitudes of about 40,000 ft. As the low pressures and temperatures above 8,000 ft are hazardous for humans, aircraft require systems that create acceptable conditions for passengers. Furthermore, aircraft also land in very humid, dry, hot, or cold regions. The Environmental Control System (ECS) serves to cope with these conditions and to create an air and pressure environment in which humans can survive and feel comfortable. Because every system that needs to be ventilated obtains its air from the ECS, the ECS has about 25 to 30 interfaces with other systems such as flight warning, cockpit display, or other avionics systems. (In Appendix A, we provide a number of examples of such interfaces with other (sub)systems as well as further technical information.) The ECS consists of several subsystems, such as the ventilation control system, the pressure control system, the temperature control system, and the air conditioning packs. An air condition pack, for instance, pressurizes the cabin and introduces oxygen, and is also able to control temperature and humidity to a comfortable level. Design requirements for air condition packs thus relate to the comfort of the passengers (e.g., pressure, oxygen, humidity, ratio of fresh to circulated air) as well as efficiency-related aspects (e.g., energy consumption, weight, maintenance costs, operating life). Hence, as the air conditioning system is responsible for creating vital conditions for passengers and the crew, its functions are of extreme importance. For safety reasons, modern commercial aircraft thus usually contain two to three redundant packs. In contrast to the ECS in general, which has to interact with many other aircraft systems and therefore has a much lower degree of modularity, the air conditioning pack itself is relatively self-contained and can be integrated into the aircraft with fewer interfaces. Furthermore, design criteria for the air conditioning pack can be defined clearly, because the volume of the cabin and maximum
number of passengers is stable from the beginning of the design phase. As a result, the developing organization has higher degrees of freedom in determining the system architecture.

**Organization of the development process.** The ECS is essential to ensure that passengers feel healthy and comfortable throughout the journey, but does not contribute to the primary function of a civil aircraft (the transport of passengers or goods). Hence, the development of both an ECS and an air conditioning pack is not considered to involve core activities of an aircraft integrator and architect, and the employed technologies are not considered to be core technologies. Due to the numerous interactions with other systems, and because of the critical functions it provides, however, the final integration of an ECS into the aircraft as well as the testing of the systems is considered to be a critical task. During its early aircraft programs, Airbus collaborated with its suppliers on a “build-to-print” basis, i.e., by providing the suppliers with a large number of very detailed (ready-to-build) specifications, which enabled Airbus engineers to ensure that the suppliers understood how an “Airbus” worked and delivered exactly the components that were needed. In an evolutionary process over the last decades, ECS suppliers gained more responsibility and, based on functional specifications provided by Airbus, designed and manufactured not only components but also subsystems like an air condition pack. While Airbus engineers defined the core architecture of the interdependent subsystems such as, for example, redundancy requirements or reactions to technical failures, the suppliers were responsible for the detailed specification of their respective subsystem.

< Insert Figure 5 about here >

**Changes induced by the NSP.** Subsequent to the introduction of the NSP, the sourcing approach changed in that larger packages were assigned to the ECS suppliers, making individual suppliers responsible for entire systems (instead of only components or subsystems). This approach was intended to let Airbus order “an air condition” based on only high-level functional specifications, while granting the supplier a high level of flexibility as regards the actual system design. During the A350 program, a large Airbus supplier even was assigned with the design and development of several interconnected systems
(the ice protection system, the bleed system, the air conditioning system, and the APU) in order to benefit from simplification and weight loss, thereby also reducing nine different contracts with several suppliers to one contract with one first-tier supplier. Furthermore, testing and integration activities have likewise been outsourced to large first-tier suppliers, who are now in charge of managing lower-tier suppliers themselves. The changes described above are illustrated in Figure 5 (left panel). The above approach enabled Airbus to control the number of in-house engineers as well as procurement staff, as fewer contract negotiations with only the tier-one suppliers were necessary. It also eased coordination processes and streamlined cash flows. Dealing with only a few first-tier suppliers decreased complexity for Airbus significantly and allowed for scale efficiency, since the first tier supplier could offer single solutions for different variants of the aircraft.

**Increasing the Scope of Outsourcing: The High-Lift System**

*Technical characteristics.* The high-lift system is part of the flight control system, which enables the aircraft to maneuver in the sky. Given the high cruising speed for which the wings of commercial aircraft are designed, the high-lift system increases the lift forces of the wings to enable flight at low speeds which, for instance, allows aircraft to start from shorter runways and with a larger angle of attack, and to land on shorter runways with a lower approach speed. Using slats and flaps that are located in the front and in the rear of the wing, respectively, the increased lift is generated through the enlarged wing area and an altered wing shape. As high-lift systems also induce more drag, they are retracted during flight. In order to realize these functions, a retraction system with actuators has to be installed in the wing frame, and an electronic control system is required to regulate and monitor the kinematics. The design criteria for the high-lift system are closely related to the primary aircraft functions, i.e., to provide sufficient extra lift, to weigh as little as possible, and to require only little maintenance. (In Appendix B, we provide further technical information.) The high-lift system consists of four major components or subsystems (the slat and flap control system, the actuating system, the system mechanics, and the outer shell) that have numerous interfaces. For instance, signals from the flap and slat control system located in
the avionic compartment in the front of the aircraft need to be understood by the actuator control unit located in the wing structure. This control unit then enables the hydraulic and electric actuators to move the mechanical parts along their tracks.

**Organization of the development process.** By enabling a safe take-off and landing, the high-lift system contributes directly to the primary functions of an aircraft. Because a severe failure in this system would endanger the lives of the passengers, the impact of this system on the aircraft’s product functions is very high. Hence, to make systems absolutely fail-safe, only proven technologies are usually applied. Moreover, the high-lift system is closely connected to an aircraft’s flight control system, which relates to the core knowledge and technologies of an aircraft manufacturer and is thus highly confidential. In the case of confidential technologies or architectures, intellectual property needs to be protected, which may preclude an intense collaboration with suppliers. Likewise, the high-lift system can contribute to differentiating the OEM from its competitors by increasing the attractiveness of the aircraft for either passengers (e.g., by making flying more comfortable) or airlines (e.g., by decreased operating costs). A differentiating factor induced by the high-lift system, for example, is a mechanism that triggers blast compensation, which keeps passengers from getting sick. Finally, and in contrast to, for instance, an air condition, a high-lift system cannot be supplied as a finished and tested system, because it has to be attached to the aircraft to unfold its function. Put differently, there is no need for “the best high-lift system,” but for an aircraft which safely accomplishes its primary function. Similar to the case of the ECS, Airbus used to collaborate with its suppliers on a build-to-print basis during its early aircraft programs. Over the course of several decades, Airbus then started to source most of the structural, hydraulic, mechanic, and electronic components from external suppliers. The design of the systems and subsystems, however, as well as the final assembly and testing of the high-lift systems continued to take place within the Airbus Center of Excellence Wing/Pylon in Bremen, Germany.

**Changes induced by the NSP.** Even though the high-lift system is also part of the Equipment & Systems domain, in which the NSP was initiated, the sourcing approach that Airbus followed subsequently was slightly different (see Figure 5, right panel). While suppliers were also involved earlier
in the development process, the scope of tasks that were outsourced to them increased to a much lesser degree than in the ECS domain. Because the architecture of the high-lift system is regarded as a core technology, it is designed in-house entirely. Hence, while suppliers were mainly responsible for components prior to the NSP, Airbus subsequently started to source also some (non-critical) subsystems, e.g., computers, externally. For example, the slat and flap control system is developed by Diehl Aerospace, whereas the actuation system is provided by Moog Inc. In stark contrast to the ECS domain, however, Airbus continues to keep control and integration responsibility for most subsystems, and in certain cases even for components, rather than outsourcing the entire system to one key supplier.

Impact of the Increased Scope of Outsourcing and the Early Supplier Involvement

**General challenges.** In the following we describe the challenges that increasing the scope of outsourcing and integrating the suppliers early entailed. The challenges are summarized in Table 1. First, involving suppliers at an early stage of the development process entailed a very high level of uncertainty regarding the processes and technologies at the time the functional specifications are written. This implied that the requirements that were given to the suppliers were often imprecise and, consequently, the suppliers needed to anticipate the expectations that the customers and the OEM would express later on. After the development had started, the requirements had to be made more precise in an iterative process, which led to more frequent conflicts with the suppliers, as it also implied costly modifications along the supply chain. Consequently, agreements had to be made with suppliers for the case that modifications of the requirements caused expensive re-work, and mechanisms such as convergence plans were introduced to amend this problem. Due to the high amount of uncertainty, however, certain elements cannot be covered by any convergence plan and may contain large conflict potential. Developing the required capabilities for writing accurate convergence plans has therefore become a large challenge for the OEM.

< Insert Table 1 about here >

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7 Here, we focus on documenting the challenges only, rather than the solutions. Moreover, because higher levels of outsourcing and early supplier involvement are rather interdependent, the resulting challenges cannot be attributed to either change alone. We address this question below.
Second, the earlier and concurrent involvement of suppliers also caused difficulties with regard to intellectual property rights. Because suppliers were asked to contribute to the design during a phase in which the final supplier selection had not been made and during which competition between several suppliers is still ongoing, all companies are eager to protect their knowledge and technologies. Having competing subcontractors collaborate under the command of a first-tier supplier is also critical due to an asymmetric distribution of power, which requires a set-up of governance mechanisms by the OEM.

Third, providing only high-level functional specifications with a small number of requirements to partner companies proved to leave a lot of flexibility to the suppliers as to how they would develop the ordered system. Airbus, in contrast, did not always know anymore what specific material was used, or how the system had been designed in detailed, and thus risks losing important component-specific knowledge. As systems have thus increasingly become a “black box”, Airbus also risks losing the capabilities to judge the suppliers’ work in both technological and financial respect. Another challenge related to the exclusive use of high-level specifications is the question of how to convey the brand image of an Airbus aircraft to the suppliers. A supplier that is able to choose any material and design approach, and that does not understand what “an Airbus” should look and work like, is likely not to deliver what the buyer expects.

Fourth, having a few suppliers develop various systems of the aircraft, the OEM needs high levels of architectural knowledge due to the high complexity and interdependence of the various systems. More fundamentally, however, the higher the level of outsourcing of interdependent (sub)systems, the more critical the integration capabilities of the system supplier become. The OEM integration task is shifted and increasingly residing on the aircraft level, whereas the first-tier suppliers now have to master the complex integration of the interdependent (sub-)systems it is responsible for. Moreover, as a first-tier supplier now needs to manage a network of sub-contractors, it needs to develop project management and supply chain management skills – tasks that various suppliers never had to deal with before. Therefore, it proved to be essential to thoroughly verify the integration capabilities, expertise, and quality standards of the designated suppliers in order to check whether they can successfully accomplish a complex
integration task. These changes to the supply chain also implied that change requests triggered by the OEM took a much long time to become implemented, and sometimes Chinese Whispers effects arose, through which the change request changed its content on its journey from the buyer to the lowest-tier supplier. Multi-tiered supply chains also made it difficult for the OEM to implement standards concerning interfaces, methods, and technologies used. In the worst case, rivalry between suppliers who had to cooperate on one system while competing on others impeded the timely and frequent exchange of information that is key to collaborative development.

Fifth, the increasing responsibilities of suppliers as well as the management by one large first-tier supplier triggered a consolidation of companies that formerly provided subsystems and components to the OEM. This led to an erosion of competition in an industry that is already characterized by few competitors, and thus increased the risk for the OEM of facing price increases.

Lastly, the way of writing high-level functional specifications has proven to highly different from the work that most Airbus engineers have been carrying out before. Because writing a detailed specification for a component requires very detailed knowledge and engineering knowhow (while other qualities become more important for writing high-level functional specifications), some of the well-trained technical Airbus staff reacted reluctantly to the high level specifications they were assigned to give out according to the new policy.

**Comparison across systems.** In the two systems in our sample, the different challenges described above materialized in different ways. We point to three main findings. First, as a general observation, the impact of the mentioned challenges has been stronger in case of the ECS, where the scope of outsourced activities was larger than in the case of the high-lift system. For instance, the larger the packages are that a supplier is supposed to develop, the larger the resulting supply chains are, the more imprecise are the up-front requirements, and the less component-specific knowledge can be retained by the OEM over time. In the context of the high-lift system, in contrast, the challenges were overall less pronounced. Given that the way of supplier involvement was adjusted similarly across all systems, this intriguing finding suggests that the scope of outsourcing seems to play a moderating role in affecting the magnitude of the potential
challenges. Second, the challenge of granting the suppliers sufficient flexibility to innovate freely while balancing it with measures to make sure that Airbus eventually got what it wanted, has proven to be much more frequent in the case of the ECS. This finding suggests that the scope of outsourcing, at least from a certain level onwards, can create additional problems that seem to be independent from the way the suppliers are involved. Third, in the context of both systems, suppliers struggled due to a lack of supply chain and project management capabilities, suggesting that these challenges are a result of increasing the level of outsourcing rather than the degree by which it is increased.

DISCUSSION AND CONCLUSION

Which paths firms (should) take if they want to transform themselves from integrated producers of complex systems into systems integrators? In this paper, we have argued that such transformations necessarily involve (1) increasing the level of outsourcing by shifting larger packages to suppliers, and (2) involving suppliers earlier in the systems development process. But are the challenges that a firm will likely face affected by the transformational path that the firm follows? In other words, should firms first involve their suppliers in early development phases, and then outsource further activities to the suppliers? Or should they first shift larger packages to their suppliers, and only later involve the suppliers in early phases? Put differently, how can firms ensure successful systems integration despite ramping up early supplier involvement?

By addressing these questions, this paper intends to contribute to extant work on complex product systems (e.g., Davies 1997; Hobday and Rush 1999; Davies and Brady 2000) and the economic relevance of systems integration (e.g., Brusoni et al. 2001) that has provided understanding of the requirements and the potential benefits and pitfalls of R&D outsourcing. Our case study of the changes that occurred in Airbus’ Equipment & Systems area adds to these lines of research by documenting the paths that Airbus followed when increasing the level of outsourcing and supplier involvement, and the challenges that the firm had to deal with. The firm’s policy to foster higher levels of outsourcing (the New Systems Policy)
which became effective only a few years ago allowed us to probe into the specific ways in which the directive was implemented.

The analysis we presented above provides a number of insights. First, it suggests that increasing the level of outsourcing – independent from how large the potential gains might be – is not suited for any system and can entail tremendous challenges. Despite the overall directive to intensify outsourcing, Airbus realized that significant differences across systems preclude treating them identically, resulting in outsourcing levels being defined on a system-by-system basis. Moreover, we found that these decisions also seem to be affected by industry-specific criteria that extant research has not pointed out explicitly. These criteria that may induce the OEM to remain involved in lower-level design and integration tasks include the cases that a system is very critical with regard to safety considerations, that intellectual property rights need to be protected, or that the system’s functions can contribute to a differentiation of the overall aircraft.

Second, our analysis also suggests that as an OEM is “moving up the V,” supplier relationships need to evolve to black box integration (Dyer and Singh 1998; Karlsson et al. 1998; Sobrero and Roberts 2001). In addition, even though the level of outsourcing was significantly higher in the case of the environmental control system, we did not find any basic differences to the way suppliers were integrated in the high-lift domain, suggesting that once suppliers become responsible for the design of subsystems, black box integration becomes more prevalent. Our findings also relate to Karlsson’s (1998) insight that black box integration cannot replace, and may likely even intensify, the need for close coordination and communication between the OEM and the supplier. One of the reasons is that the OEM has to retain a certain degree of component-specific knowledge, which can be accomplished through strong ties with the supplier. Another reason is that even when entire systems are developed by suppliers, the core objective of the OEM to eventually integrate all systems into the final aircraft requires a common understanding of functional purposes, interfaces, and quality requirements, which in turn can only be defined by the OEM. Finally, involving suppliers in early phases of the systems development process mandates high levels of coordination and adaptation throughout iterative design cycles. Similar to Karlssons’s (1998) results,
however, Airbus’ engineers seem to conceive these changes as inefficient, most likely due to the fact that the flow of architectural knowledge in this relationship is directed toward the suppliers.

Third, and related to the prior argument, there seem to be limits to the level of outsourcing that result from the distribution of capabilities across the buyer-supplier network. Many suppliers, for instance, are used to dealing with the complexity of components and subsystems; in order to design and integrate entire systems, or even groups of interconnected systems, however, they may lack the necessary architectural knowledge (Henderson and Clark 1990). Moreover, suppliers may also lack the capabilities for managing large projects as well as other suppliers. Likewise, suppliers might not possess enough brand-specific knowledge (how “an Airbus” looks and feels like). This lack of competence, in turn, requires the OEM to initially provide suppliers with detailed instructions and support, thereby incurring significant efficiency losses. A second reason, in line with the argument of Brusoni et al. (2001), is that a systems integrator must retain a sufficient amount of component-specific knowledge in order to be able to integrate all systems into the aircraft. Moreover, as the OEM evolves from a producer (and developer) of complex systems into an integrator of systems that are provided by other firms, it needs to build up capabilities for supplier management, which may include, for instance, to provide specifications in a way that makes them understandable for the supplier. In sum, thus, it seems that the exact limit to the scope of outsourcing and supplier involvement cannot be derived exactly up-front. Thus, an experiential approach, and a gradual and systematic transfer of responsibilities might help define, and over time extend, the limit of outsourcing, while granting the OEM and its suppliers sufficient time to develop absorptive capacity (Cohen and Levinthal 1989) and relevant capabilities.

Using a case study of the aircraft industry, the goal of this paper was to refine our understanding of the approaches and challenges of increasing the level of R&D outsourcing in complex systems development. While aircraft manufacturing is in many respects a special context, it likewise shares many similarities with other CoPS industries, in which firms are facing similar challenges. Clearly, more empirical work needs to be done to deepen and extend our analysis. For instance, one could explore the conditions under which faster or more radical increases in R&D outsourcing could become viable, and the
actions organizations take when doing so. A different extension would be to focus on the solutions that organizations apply to solve the (coordination, cooperation, or competence-related) challenges that higher levels of R&D outsourcing entail. In this context, it would be highly interesting to study how firms can organize in order to define and implement higher levels of outsourcing. In other words, how can firms learn how to define a viable definition of R&D labor?

In a broader sense, this paper also touches upon these learning challenges that higher levels of R&D outsourcing in complex systems entail. It suggests that the complexity of the problem, and the multitude of challenges that firms are facing, preclude any up-front definition of comprehensive solutions. Instead, two aspects characterized the adaptive response of the organization we studied: a differential treatment of different systems and subsystems, and the substantial time required for experiential learning by both suppliers and the OEM alike. In this respect, the approach we documented bears resemblance to the experiential procedure of test pilots that push the performance envelope of their aircraft beyond the established limits. In a similar manner, carefully pushing the organizational envelope – moving beyond established supply structures in an incremental manner – also appears to be a viable approach to foster higher-level outsourcing in complex product systems.
REFERENCES


Figure 1: The V-Model of Complex Systems Engineering

Product
(e.g., transport passengers safely and comfortably)

Requirements for interacting systems
(e.g., provide air and climate control)

System requirements
(e.g., provide air conditioning)

Subsystem requirements
(e.g., provide pressure control)

Component / module requirements
(e.g., provide control computations)

Test of components / modules
(e.g., test control computer)

Test of subsystems
(e.g., test pressure control functions)

Test of interacting systems
(e.g., test air conditioning and APU)

Test of systems
(e.g., test air conditioning system)

Test of assembled systems
(e.g., test systems when assembled to the aircraft)

Final product test
(e.g., ground and flight tests)

Figure 2: Levels of Outsourcing and Systems Integration

Scope of Outsourcing
• OEM outsources entire (sub)systems
• Suppliers become responsible for larger, integrated packages
• Supply chains differentiate

Early Supplier Involvement
• OEM integrates suppliers in earlier phases
• Concurrent engineering and design iterations become more common
• Buyer-supplier relationships entail "black boxing" and functional specifications
Figure 3: Evolution of Airbus’ “Make” Share

<table>
<thead>
<tr>
<th>Past</th>
<th>Present/Future</th>
</tr>
</thead>
<tbody>
<tr>
<td>Platform assembly</td>
<td>Airbus</td>
</tr>
<tr>
<td>Large-scale integration</td>
<td>Airbus</td>
</tr>
<tr>
<td>Value-added parts and assemblies</td>
<td>Tier 1</td>
</tr>
<tr>
<td>Make-to-print parts and assemblies</td>
<td>Airbus</td>
</tr>
<tr>
<td>Raw materials</td>
<td></td>
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</tbody>
</table>

Figure 4: Early Supplier Involvement in the Equipment & Systems Domain

<table>
<thead>
<tr>
<th>Past</th>
<th>Today:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concept</td>
<td>Joint concept phase</td>
</tr>
<tr>
<td>Supplier concept phase</td>
<td>Supplier selection</td>
</tr>
<tr>
<td>Supplier selection</td>
<td>Joint definition phase</td>
</tr>
<tr>
<td>Supplier selection</td>
<td>Contract award</td>
</tr>
<tr>
<td>Supplier selection</td>
<td>MG 3: Begin of concept phase; short list of potential suppliers; joint work in JCP teams</td>
</tr>
<tr>
<td>Supplier selection</td>
<td>MG 4.1: Selection of risk-sharing partners; freeze of aircraft performance</td>
</tr>
<tr>
<td>Supplier selection</td>
<td>MG 4.2: Industrial launch; start of definition</td>
</tr>
<tr>
<td>Supplier selection</td>
<td>MG 5: Supplier selection</td>
</tr>
<tr>
<td>Supplier selection</td>
<td>MG 6: Start of production</td>
</tr>
<tr>
<td>Supplier selection</td>
<td>MG 7: Freeze of definition</td>
</tr>
<tr>
<td>Supplier selection</td>
<td>MG 9: Final assembly line</td>
</tr>
<tr>
<td>Supplier selection</td>
<td>MG 11: Flight test and certification</td>
</tr>
</tbody>
</table>
Figure 5: Raising the Level of Outsourcing in the Equipment & Systems Domain

<table>
<thead>
<tr>
<th>A: Environmental Control System</th>
<th>B: High-Lift System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Groups of systems</td>
<td>Increase due to New Systems Policy</td>
</tr>
<tr>
<td>System</td>
<td>Increase due to New Systems Policy</td>
</tr>
<tr>
<td>Subsystem</td>
<td>Evolutionary increase</td>
</tr>
<tr>
<td>Component</td>
<td>Evolutionary increase</td>
</tr>
<tr>
<td>Material</td>
<td>Material</td>
</tr>
</tbody>
</table>
Table 1: Changes Induced by the New Systems Policy (NSP)

<table>
<thead>
<tr>
<th>Characteristics of the OEM-Supplier Interaction</th>
<th>Pre-NSP</th>
<th>Post-NSP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suppliers develop components or subsystems</td>
<td>• Suppliers develop components or subsystems</td>
<td>• “Bigger” – suppliers develop systems or groups of systems</td>
</tr>
<tr>
<td>OEM writes functional specifications</td>
<td>• OEM writes functional specifications</td>
<td>• “Earlier” – suppliers involved earlier (in concept phase instead of design phase)</td>
</tr>
<tr>
<td>Suppliers involved from design phase on (when concept is stable)</td>
<td>• Suppliers involved from design phase on (when concept is stable)</td>
<td>• OEM writes top-level functional specifications</td>
</tr>
<tr>
<td>OEM manages broad supplier base</td>
<td>• OEM manages broad supplier base</td>
<td>• Suppliers responsible for lower-level specifications, (some) test and integration work and certification on systems level</td>
</tr>
<tr>
<td>First-tier supplier manage lower tier suppliers</td>
<td>• First-tier supplier manage lower tier suppliers</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Challenges</th>
<th>Pre-NSP</th>
<th>Post-NSP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less potential to access specialized knowledge</td>
<td>• Less potential to access specialized knowledge</td>
<td>• Earlier involvement (high level of specification uncertainty)</td>
</tr>
<tr>
<td>More in-house development capacities necessary</td>
<td>• More in-house development capacities necessary</td>
<td>• Imprecise requirements</td>
</tr>
<tr>
<td>Large in-house supply chain management necessary</td>
<td>• Large in-house supply chain management necessary</td>
<td>- Suppliers need to anticipate expectations</td>
</tr>
<tr>
<td>Less potential to save costs due to lower scale efficiencies</td>
<td>• Less potential to save costs due to lower scale efficiencies</td>
<td>- Later modifications</td>
</tr>
<tr>
<td>No possibility to concentrate on core business as systems integrator</td>
<td>• No possibility to concentrate on core business as systems integrator</td>
<td>- Agreements for later modifications necessary</td>
</tr>
<tr>
<td>Later involvement of suppliers:</td>
<td>• Later involvement of suppliers:</td>
<td>• Suppliers protect their IP</td>
</tr>
<tr>
<td>Unused potential for product innovation and quality improvement because of later access to supplier knowledge</td>
<td>- Unused potential for product innovation and quality improvement because of later access to supplier knowledge</td>
<td>• Increased supplier responsibility</td>
</tr>
<tr>
<td>Less potential to reduce lead times</td>
<td>- Less potential to reduce lead times</td>
<td>• OEM risks to lose systems integration and component-specific knowledge</td>
</tr>
<tr>
<td>Early involvement (high level of specification uncertainty)</td>
<td>• Early involvement (high level of specification uncertainty)</td>
<td>• OEM can hardly judge supplier work (technologically and financially)</td>
</tr>
<tr>
<td>Imprecise requirements</td>
<td>• Imprecise requirements</td>
<td>• Suppliers need brand-specific knowledge</td>
</tr>
<tr>
<td>Suppliers need to anticipate expectations</td>
<td>• Suppliers need to anticipate expectations</td>
<td>• Supply chains</td>
</tr>
<tr>
<td>Later modifications</td>
<td>• Later modifications</td>
<td>• Suppliers need supply chain knowledge</td>
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<tr>
<td>Agreements for later modifications necessary</td>
<td>• Agreements for later modifications necessary</td>
<td>• Competition between suppliers impedes collaboration</td>
</tr>
<tr>
<td>Suppliers protect their IP</td>
<td>• Suppliers protect their IP</td>
<td>• Chinese Whispers effect</td>
</tr>
<tr>
<td>Increased supplier responsibility</td>
<td>• Increased supplier responsibility</td>
<td>• Modifications take long</td>
</tr>
<tr>
<td>Suppliers need brand-specific knowledge</td>
<td>• Suppliers need brand-specific knowledge</td>
<td>• Hard to implement standards along the supply chain</td>
</tr>
<tr>
<td>Supply chains</td>
<td>• Supply chains</td>
<td>• Modifications take long</td>
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<tr>
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</table>
APPENDIX A: The Environmental Control System

The air conditioning pack is a subsystem of the ECS (other subsystems are the bleed air system, the anti-icing devices, the electronic controls, and the galley cooling devices). The air conditioning pack itself consists of several components (e.g., a heat exchanger, the air cycle machine, a water extraction device, and controlling units). For pressurization and temperature control, air conditioning packs can either extract bleed air from the aircraft engines or (a more modern approach) use electrical energy to compress the air and adjust the temperature (Engmann 2009). Unlike Boeing in its 787 “Dreamliner” program, Airbus continues to use bleed air for pressurization and temperature control – a proven technology that has been pursued since the first Airbus program (the A300).

The air conditioning pack exhibits several important interfaces with other ECS subsystems. For instance, the pack needs to be connected to the bleed air system, and the pressure and temperature of the bleed air are important determinants for the layout of the pack. The heat exchanger comprises a connection to the ambient environment, including control flaps to alter the outside air flow rate. This interface has to be embedded into the fuselage structure and thus into the aerodynamic layout at an early stage of aircraft development. At the same time, the size of the interface with the ambient environment determines the maximum cooling factor for the air conditioning system (Moir and Seabridge 2008). A further important interface concerns the cabin outlets, where the conditioned air enters the cabin through a ducting system. Depending on the cabin size, pressure and temperature losses have to be considered during the design phase. The eyeball vent system, where cabin outlet ducts are located overhead each passenger seat, is attached to the main cabin air system. The controlling unit also has several interfaces with the air conditioning pack in order to control the mixing temperatures and pressures. Using this unit, the crew can alter the cabin temperature. The system has to control the air flows throughout the pack, and add electric heaters when the heat of the bleed air is not sufficient (e.g., in very cold regions). To prevent a hazardous over-pressurization of the cabin, an independent system controls the cabin pressure. A flap system opens when air has to flow out. In case of system failure, emergency valves open when a certain pressure is reached. As this system acts independently of the air conditioning pack, the complexity of the two subsystems is reduced. The pack itself does not have to control the pressurization (Moir and Seabridge 2008).

Figure A1: Exemplary Air Conditioning System Architecture

(Cockpit view; Source: Airbus A380 Systems Briefing for Pilots)
APPENDIX B: The High-Lift System

In addition to the information provided in the main text, the high-lift system is also affecting the aerodynamic lift forces through the gaps between the trailing edge and the flaps, as well as through the gaps between the leading edge and the slaps. Moreover, in recent aircraft development programs, some hydraulic actuators have been replaced by electric motors. Independent from the underlying actuation principle, the pilot is controlling the flap and slat angle of retraction from the cockpit.

As described in the main text, the high-lift system consists of different components (the slat and flap control system, the actuating system, the system mechanics, and the outer shell). The slat and flap control system receives the signals coming from input devices as well as from the wings and emits output signals according to the required changes. The actuating system includes the hydraulic or electric actuators, transmissions, and intermediate gearboxes, as well as the motor-controlling unit. The third major component group combines the system mechanics, i.e., the track system which is used to guide the flaps and slats along to their designated position. The fourth important component group is the outer shell (or skin/fairing) that is mainly designed with fiber-reinforced composites in order to save weight.

The different components of the high-lift system have to be integrated with the aerodynamic frame of the aircraft and have to be considered at the time of the first aircraft design, as primary aircraft functions like flying or take-off and landing can only be developed in an integrated manner (Moir and Seabridge 2008). Thus, in designing the high-lift system, various trade-offs need to be resolved. For instance, the track fairings need to be integrated into the aerodynamic model of the overall aircraft, and the drag that is induced by them has to be considered. The leading edge of the wing, and thus also the front part of the slat system, has to incorporate anti-icing devices. These devices also have to be integrated into the overall system architecture. Moreover, other subsystems that are located within the wing structure (e.g., pipes and cable beams) compete for space with parts of the high-lift system (e.g., actuators).

Figure B1: Exemplary High-Lift System Architecture

(Cockpit view; Source: Airbus A380 Systems Briefing for Pilots)
Figure B2: Major Components of the High-Lift System (in orange)

(Source: Airbus A380 Systems Briefing for Pilots)