CREATING HIGH PERFORMANCE ENTERPRISES

by

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Abstract

How do enterprises successfully conceive, design, deliver, and operate large-scale, engineered systems? These large-scale projects often involve high complexity, significant technical challenges, a large number of diverse stakeholders, distributed execution, and aggressive goals. In this context, simultaneously meeting technical performance, cost, and schedule goals effectively and efficiently is a serious challenge. In fact, it is rarely accomplished. The nature of an enterprise contributes to this challenge. Enterprises are interorganizational networks with distributed leadership and stakeholders with both common and diverse interests. They are unique from traditional levels of analysis in organizational studies, and in general their behavior is not well understood. They are a prevalent form of organizing work in these large engineering projects, where one organization simply does not have the capability or willingness to take on the entire project by themselves. This work explores the factors that distinguish high performance enterprises from those that are less successful in these large-scale projects.

The setting for this research is programs in the aerospace industry. A comparative case study method was used to study nineteen programs spanning the U.S. (mainly defense) aerospace industry in order to develop grounded theory regarding contemporary program execution strategies and distinguishing attributes. Drawing on prior research with high performance teams, several characteristics were explored and refined, eventually resulting in identification of ten best practices. The contribution of this work is codification of these best practices into a coherent framework of complementary elements relating to particular outcomes.

The framework articulates three drivers of individual and systemic behaviors: a system of distributed leadership, informal and formal structures. The framework addresses the role each of these plays in enterprise performance. The synergistic combination of the elements enables enterprises to execute planned activities, leverage emergent opportunities, and deal with unforeseen circumstances. For enterprises involved in large-scale engineering projects, these capabilities are a necessity for success. In addition to an academic theory, this framework can be considered an architectural design for high performance enterprises. Putting this enterprise architecture into practice has important implications for both corporate and program management.

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Biographical Note

Alexis Stanke worked on her PhD from 2004 to 2006 with the support of the Lean Aerospace Initiative (LAI) consortium. She has worked with LAI for since 2000, first as a Master's student, then as a Research Engineer on the full-time staff before beginning her doctoral work. As part of the research staff, she worked on curriculum development, university outreach, and developing and applying enterprise level lean tools. During her time at LAI she had numerous opportunities to teach and facilitate a variety of audiences from undergraduate students to executive teams. She was one of the original LAI Lean Academy® course developers and instructors, and she continues to contribute to both the curriculum development and delivery. She helped develop (and co-authored) the "Enterprise Value Stream Mapping and Analysis" methodology, including implementation with executive teams in several different organizations.

Prior to LAI, Alexis spent short stints doing structural and manufacturing engineering with Boeing on the F/A-22 program, doing production engineering with Exxon on offshore oil platforms, and doing quality assurance with the Advanced Manufacturing Center at New Mexico State University. Alexis's professional interests include systems architecture and design, systems engineering, program management, organizational design, and enterprise strategy.

She received a SM in Aeronautics and Astronautics from the Massachusetts Institute of Technology in 2001 focused on systems engineering. She graduated with Distinction in University Honors from New Mexico State University in 1998 with a BS in Mechanical Engineering and minors in Mathematics and Spanish. Stanke was a fellowship recipient at MIT and the College of Engineering Outstanding Senior at NMSU. She is a member of several national honors societies, including Tau Beta Pi and Pi Tau Sigma.

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Introduction

This research explores how an enterprise developing a large, complex engineering system can deliver a high quality, technically superior product, on schedule, and within budget. These large-scale projects often have high complexity, significant technical risks, a large number of diverse stakeholders, distributed execution, and aggressive goals. This environment is challenging for effective and efficient execution, but does that mean that projects in this environment cannot be successful? There are a small number of exceptional projects that have managed to meet all of their commitments in terms of cost, schedule, and technical performance simultaneously. The evidence presented in this thesis is organized into a framework of factors that differentiate these high performing projects from the majority of others that struggle in the same environment.

In particular, this work focuses on large-scale, engineering development projects in the aerospace industry. In the aerospace setting, such projects are referred to as *programs* (the generic term *project* is commonly used for smaller-scale efforts). These programs are also enterprises. In this context, *enterprise* refers to the interorganizational network contributing to the common purpose of the development and delivery of a system. As a result of the interorganizational nature of enterprises, they have distributed responsibility and leadership, and they have stakeholders with both common and diverse interests. Throughout this work, I use the terms program and enterprise interchangeably. Programs are of particular interest because they are a main organizing unit and often represent the revenue streams for their firms since they are directly linked to customers.

The question of interest in this study is: **what are the foundational mechanisms that distinguish exceptionally successful aerospace programs?** This study aims to identify and gain an understanding of the fundamental characteristics of high performance programs, beyond the readily observable best practice heuristics. Program excellence requires an understanding of not only the observable practices, but also the relationship between practices and outcomes, the complementarities among practices, and the supporting context.

At the enterprise level, there is little work that adequately investigates the characteristics related to program performance. Somewhat related but on a smaller scale, there is quite a bit of work that examines these characteristics for teams, in settings from sports to sales to product development, and nearly everything in between. A recent example is the X-teams theory of high performance teams by Ancona, Bresman, and Kaeufer (2002). This theory is based on studying more than 150 teams with various tasks from several industries. The X-teams theory outlines five characteristics of high performance teams: external activity of team members, extensive social ties beyond the team, expandable three-tier structure, flexible membership between tiers, and internal mechanisms for execution. Of all the work on teams available, this specific theory is most relevant to this study because of the environment for which X-teams are particularly well suited: "X-teams are appropriate, first, when organizational structures are flat, spread-out systems with numerous alliances rather than multilevel, centralized hierarchies...Second, X-teams are advised when teams are dependent on information that is complex, externally dispersed and rapidly changing...Third, use X-teams when a team's task is interwoven with tasks undertaken outside the team" (Ancona et al., 2002, p. 39). These three conditions all hold true for programs. In fact, they may be more descriptive of the enterprise environment than of typical team environments. This work about teams presents a good starting point for this research, but introduces the question, **how do the team characteristics scale up to program enterprises? Are the X-team characteristics appropriate to describe an X-enterprise?**

Starting with the X-teams theory, enterprise-level issues were explored through a series of case studies. A total of 19 case studies were conducted to explore these issues and develop a theory for high performance enterprises. These cases spanned the breadth of the aerospace industry and are representative of both programs that are "best in class" as well as those that are struggling. Data from the case studies was aggregated into themes for each case and then into categories and subcategories across the cases. Ten important subcategories were identified as being cited by more than one program in the study. These subcategories were developed from observations into best practices and desired objectives. The contribution of this work lies in how the best practices are organized into a framework with sets of complementary elements related to particular outcomes driving towards enterprise performance. This framework provides greater insight into how enterprises have achieved success than simply a list of observations and "lessons learned."

This framework has three main sections: *distributed leadership actions*, *informal structures*, and *formal structures*. Together, the informal and formal structures act as *strategic leadership levers*. Each of the three organizational characteristics/capabilities drives behaviors and creates alignment in the enterprise. A system of distributed leadership actions enacts the culture of the enterprise, advancing it through consistent reinforcement. Distributed leadership results in goal congruency and an empowered workforce, giving the enterprise a robust property, where robustness is the ability to withstand or overcome adverse circumstances to maintain performance. The set of practices captured as informal structures are related to how enterprises manage unknowns and take advantage of emergent opportunities that occur in the program. The result of strong informal structures is effectiveness of outcome and a flexible enterprise, where flexibility is the ability to adapt or change in response to different circumstances without severe time, cost, or performance penalties. The formal structures are related to an enterprise's ability to manage and plan for known challenges and activities. Stronger and more standardized formal structures result in efficient execution or an agile enterprise, where agility is the capacity and capability to act quickly and easily, in the current situation. The combination of informal and formal structures in adaptive systems was described by March (1991, p. 71) who noted, "maintaining an appropriate balance between exploration [of possibilities] and exploitation [of certainties] is a primary factor in system survival and prosperity."

The codification of best practices and their organization into a framework can be considered an architectural design for high performance enterprises. As such, there are implications for contemporary program management practices as well as corporate processes and policies. But as a caveat, the appropriate organizational context for the successful adoption and sustainment of this enterprise architecture has yet to be explored.

In this thesis I first introduce the relevant literature and description of the X-teams characteristics, then describe the research methods and summary of the case studies conducted, and move on to analyze the data and construct the framework. I end with implications for moving from a theoretical framework into practical application and opportunities for future work to further develop and test the theory.

Chapter 1

Learning from Theory: From X-Teams to X-Enterprises?

Introduction

This dissertation explores how an enterprise that develops a large complex engineering system can deliver a high quality, technically superior product, on schedule, and within budget. Typically, for aerospace programs, the targets of system performance, cost, and schedule cannot be met simultaneously, resulting in zero-sum tradeoffs among them. The F/A-18E/F[1] Super Hornet is the Navy's newest fighter aircraft, and the Super Hornet enterprise managed to do what is widely considered impossible in the industry. They delivered an aircraft that met or exceeded all technical requirements, on time, and without exceeding the budget. The secrets to success of high-performing programs like the Super Hornet are not often well understood and, as a result, they remain elusive to those who try to replicate the results.

Ancona, Bresman, and Kaeufer (2002) describe a similar phenomenon with high performance teams. They call these externally oriented teams, which manage across boundaries and achieve exceptional performance, X-teams. Their theory is based on studying more than 150 teams with

[1] Following convention, in the aircraft name, F/A indicate fighter (F) for air-to-air capability and attack (A) for air-to-ground capability; the letters E and F designate single-seat and two-seat versions of the aircraft respectively.

various tasks from several industries. For the 45 product development teams in the study, X-team characteristics were predictors of adherence to budget and schedule, as well as innovation (Ancona et al., 2002). The X-teams theory outlines five characteristics of high performance teams: external activity, extensive external ties, expandable three-tier structure, flexible membership between tiers, and internal mechanisms for execution.

In this thesis, I will develop a theory of high performance enterprises based on an in-depth case study of the F/A-18E/F and 18 additional smaller case studies of other aerospace programs. In the remainder of the first chapter, I will describe the X-teams theory by placing it in the context of relevant literature. I will also use the F/A-18E/F case study to further motivate and suggest an enterprise-level application of the theory. In the second chapter I will review my research methods and place the study in the context of other work. The third chapter covers the data collected from the case studies. Next, I present an analysis of the case data and refine the enterprise-level analogies of the X-team characteristics in the fourth chapter. The fifth and sixth chapters introduce, develop, and consider application of a framework for high performance enterprises. Each chapter contributes to the goal of this work: empirically based, enterprise-level theory development to characterize the foundational mechanisms that distinguish highly successful enterprises. As a matter of framing, I turn now to a brief introduction of the uniqueness of an enterprise level of analysis.

Level of Analysis

In organizational studies, three levels of analysis are generally considered: individual, group, and organization. There is a basic scaling effect between the levels of analysis where groups are small collections of individuals and organizations are large collections of individuals, or even collections of groups; both groups and organizations are unified by common goals. The levels are essentially nested, and there are discrete breaks between them where there are different observable patterns of organizing and managing individual actions. A team sits at the group level of analysis, but teams differ from groups in that they have a specific purpose and generally exist for a finite period of time to achieve that purpose. A team has been defined as "a small number of people with complementary skills who are committed to a common purpose, common performance goals and approach for which they hold themselves mutually accountable" (Katzenbach & Smith, 1993, p. 45).

Considering the same sort of scaling that exists from groups to organizations, the logical analogous jump from teams would be to large-scale projects that involve many teams working towards grander common goals in such a way that they are mutually accountable. Aerospace programs are a good example of this. The scale and complexity of the systems they develop and produce is sufficiently large to require many teams integrating their efforts to achieve their goals. Other than size, aerospace programs have some important similarities with the team level. Teams are generally ten to twenty people, but programs involve coordination of hundreds to thousands of individual participants, and tens to hundreds of teams (Murman *et al.*, 2002).

The next question is, if teams fit at the group level of analysis, do programs fit at the organizational level? This seems like a reasonable assumption, but it is not the case. Organizations are generically a large number of people unified by common goals. Programs seem to fit within this description, but confusion arises because colloquially, the word "organization" is associated with other characteristics such as clear boundaries and leadership with an encompassing span of control. Literature on organizations generally follows these assumptions of an organization being a single unit with one span of control and, although it is relevant in many ways, the term must be carefully applied to programs because they are sufficiently distinct from this narrower view of an organization. To emphasize this distinction, I submit that programs fall within a uniquely identifiable level of analysis. Programs generally involve teams from many different organizations; in fact they involve large subunits of organizations acting as a coordinated *interorganizational network*. Interorganizational networks are a relatively newer level of analysis that has begun to receive attention and traction in organizational studies (Borgatti & Foster, 2003; Powell, 1990).

Programs fit squarely in the level of interorganizational networks, but like teams are often more specific and focused than networks in general. Just like the relationship between teams and groups, programs, or more broadly enterprises, are a more focused instance of interorganizational networks. Enterprises have a specific purpose, distributed leadership, and stakeholders with common and diverse interests. This distinction is clarified in Figure 1 below. Enterprises are of interest in how they can build on existing theory and research, but also in how they are distinct from traditional levels of analysis and not particularly well understood.

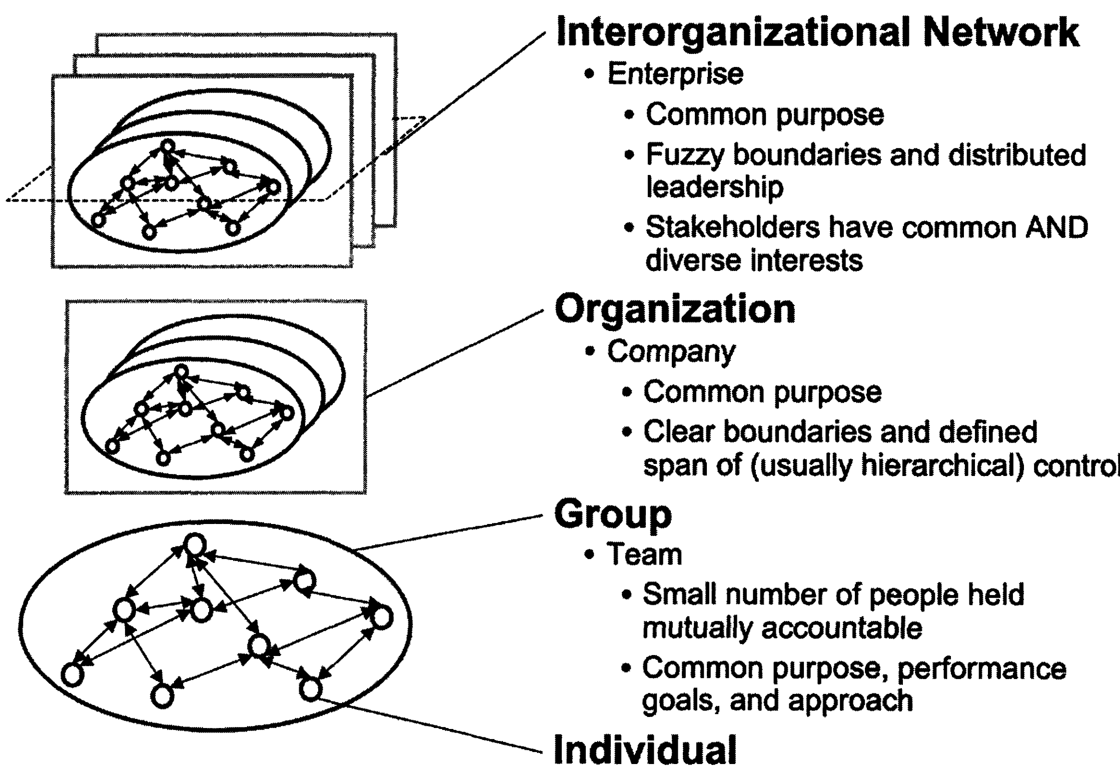

Figure 1. Levels of Analysis

There are a few important challenges to recognize in moving between levels of analysis, especially in scaling concepts from the team to enterprise level. One is that programs are highly dispersed, facing issues of communication richness and information exchange (Daft & Lengel, 1986). Another is that teams are based on interpersonal relationships and face-to-face interactions, whereas programs are based on both interpersonal relationships and interorganizational relationships. As a result, teams and programs have different issues with regard to power and politics as well as coordination. Finally, whereas teams often span cross-functional boundaries, program enterprises span cross-organization and cross-cultural boundaries (Murman et al., 2002). These will be important considerations in refining the understanding of what X-team characteristics look like at the enterprise level.

Characteristics of X-Teams

Five main characteristics describe how X-teams differ from more traditional teams. The five hallmark characteristics of X-teams are: external activity, extensive ties, expandable structure, flexible membership, and internal mechanisms for execution (Ancona et al., 2002). These characteristics were identified after studying 169 teams spread (unequally) across a telecommunications company, an educational consulting company, five high-tech product development companies, a multinational oil company, a computer manufacturer, and three units of a large pharmaceuticals company (Ancona et al., 2002). Higher customer satisfaction ratings, higher manager ratings (for performance and innovation), and adherence to budget and schedule were some of ways X-teams differed from traditional teams in terms of measures of success (Ancona et al., 2002).[2] In the following sections, these characteristics are described for the team level, and then elaborated with specific attention towards the enterprise level.

[2] Not all measures of success were used to evaluate the performance of every team in the study.

External Activity

At the team level, *external activity* involves utilizing information external to the team to: manage upward (ambassadorial), identify knowledge and expertise (scouting), and manage laterally (task coordination) (Ancona & Caldwell, 1992). The three types of external activities serve different purposes: The goal is not only to incorporate these activities into the team's tasks, but also to know when to utilize which type of activity to maximize effectiveness (Ancona et al., 2002). Ancona and Caldwell (1992) have established that teams engaging in external activity create a virtuous cycle over time where the external activity reinforces the internal processes and the team's performance.

These external activities are forms of boundary spanning activities. Boundaries are the domains where an entity interacts with its environment (Scott, 1992). Boundary activities occur anywhere a boundary is created, that is, they can occur at various levels (individual, team, organization, etc.). An entity engages in boundary activities to create and maintain its boundaries and to manage interactions across those boundaries (Cross *et al.*, 2000).

An enterprise is an interorganizational network, consisting of separate organizational entities working together. Following the previous definition, the boundary of the enterprise is with its external environment, but the interorganizational nature of enterprises adds many interfaces across the organizations. Interfaces are shared organizational boundaries across which information is passed (cf. IEEE, 1992). These interfaces are boundaries from the organizational perspective, but they are internal to the enterprise. To clarify, I will use the term interface to refer to the shared boundaries *internal* to an entity and the term boundary when referring to where the entity interacts with its *external* environment. In literature on interorganizational relations (see Whetten, 1981 for a review), interorganizational trust (Gulati, 1995; Zaheer *et al.*, 1998), and interorganizational learning (Doz, 1996; Larsson *et al.*, 1998), it is widely recognized that the same boundary spanning activities used externally are appropriate and required for spanning interfaces between organizations. In moving from the team level to an enterprise scale, the boundary spanning characterized as external activity becomes internalized across the interfaces in the enterprise. Managing internal interfaces is a significant enterprise challenge, and it increases the complexity of boundary spanning activity since it occurs both internally and externally at the enterprise level. Although internal interfaces are distinct from external boundaries, the types of activities that occur across them are very similar and will be referred to as boundary spanning activity. This is not to cause confusion, but to maintain consistency with the existing body of work on boundary spanning.

As more and more boundary activities are required both at external boundaries and internal interfaces, these activities become the responsibility of more and more individuals in the enterprise. As more individuals are selected and prepared to take on these roles, their common characteristics become important. Naturally, specific characteristics vary by activity but, in general, boundary spanners have a high perceived competence and they tend to have strong connections on both sides of the boundary (Tushman & Scanlan, 1981b). They are also able to manage the information requirements of their on-going projects and their boundaries. Although, to an extent, some individuals are more inclined towards boundary spanning activity, specific boundary spanning skills can be taught, nurtured, and developed. The roles of boundary spanners can also be codified in position descriptions. Effective boundary spanning activity relies on strengthening the characteristics of individual boundary spanners, as well as formalizing the roles of boundary spanners. This is relevant to the activities used across both boundaries and interfaces of an enterprise.

Extensive Ties

Boundary spanning activities require *extensive ties*. Ties are created by individuals as they build their social (interpersonal) networks; these networks can be utilized to identify and seek out useful people with different perspectives (Hansen, 2002). Social networks are composed of both strong and weak ties (Burt, 1992; Granovetter, 1973, 1983). The strength of tie is determined by frequency of contact, emotional intensity, and general closeness (mutual confiding) of the relationship (Granovetter, 1973). The strength of tie is not determined by, but is generally related to, the amount of common knowledge shared between individuals (Hansen, 1999). Weak ties are good for identifying unique knowledge (Granovetter, 1973, 1983; Hansen, 1999), but strong ties facilitate cooperation and transfer of complex knowledge (Krackhardt, 1992).

In a team, each member manages their external ties, and each individual network is strongly tied together by interaction among the members. It is the individual networks, linked by participation in the team, which constitutes the knowledge network of the team. The various network relations have different performance implications for the team, depending on whether they tie the team to relevant knowledge (Hansen, 2002). In order to take advantage of relevant knowledge, mechanisms must be put in place to identify and transfer the knowledge effectively. Identifying knowledge requires the development and utilization of weak ties through mechanisms such as travel allowances for professional meetings, access to technical information (books, journals, reports), and support for education (Tushman & Scanlan, 1981a, 1981b). Similarly, there are often mechanisms put in place to facilitate the transfer of complex knowledge through the strong ties holding the team together, such as person-to-person communication (Allen *et al.*, 1980; Imai *et al.*, 1985), physical collocation (Allen, 1977; Tyre & von Hippel, 1993), and frequent information transfer (Allen, 1986; Carter & Miller, 1989).

At the enterprise scale, the knowledge network is expansive and more loosely tied within the enterprise, which is taxing on the systems used for coordination. In addition to the coordination challenge, managing the knowledge network for highest leverage is not trivial. The burden of searching for relevant knowledge increases significantly when more people are involved, especially where the network has holes. Structural holes are unconnected gaps between clusters in a network (Burt, 1992). When it comes to transferring knowledge effectively, the path length of the network relations comes into play. The source and destination of knowledge may not be directly connected and, in fact, the further apart they are, the more difficult it is to transfer knowledge between them (Hansen, 2002).

Another challenge at the enterprise level is utilizing the diversity of knowledge effectively. While diversity in social ties contributes to a higher variety of knowledge available, the discomfort and lack of commonality created by this diversity may overwhelm the ability to aggregate the knowledge usefully (Gruenfeld *et al.*, 1996). The existence of common knowledge is a prerequisite for effective communication between different specialists (Demsetz, 1991). In general, the wider the scope of information being shared and integrated, the lower the level of common knowledge, and the more inefficient the communication and sharing activity (Grant, 1996). Although diversity may lead to more valuable information sharing (Cummings, 2004), it is also likely to require additional effort to acquire that information.

In addition to the increased scale of the knowledge network, ties exist between organizations as well as between individuals at the enterprise level. Interorganizational relationships "are the enduring transactions, flows, and linkages that occur among or between an organization and one or more organizations in its environment" (Oliver, 1990, p. 241). Interorganizational ties form when individual ties become institutionalized so they are not dependent on the particular individuals involved in the relationship. One of the primary enterprise-level challenges for programs is the integration of knowledge across these interorganizational relationships. Effective knowledge sharing is an important enabler of enterprise performance, whether within an organization or between organizations (Nonaka, 1994).

Just as strong and weak ties have roles to play in sharing knowledge at the individual level, strong and weak ties between organizations have similar roles in knowledge sharing. Although knowledge sharing is an inherently individual activity, it is not only the relationship that gets institutionalized, but the strength of the ties as well, which impacts subsequent knowledge transfer between the organizations. Weak ties have benefits in searching for knowledge and transferring straightforward, codified knowledge; strong interorganizational ties have benefits in transferring complex, noncodifiable, dependent knowledge (Hansen, 1999). In enterprises, individual and organizational ties play a role in the identification, transfer, and utilization of knowledge.

Expandable Structure

The informal configuration of a large, complex team can be seen as a multi-tiered, *expandable structure*. It balances separateness of the team (a clear boundary and dense internal ties) required for team identity with external interactions needed to accomplish work. An expandable structure that has been identified as particularly useful consists of three tiers: a core tier, an operational tier, and an outer-net tier (Ancona et al., 2002). The core tier team members provide the history and identity of the team, coordinate its activity, create its strategy, and make key decisions. The operational tier performs the work and is tightly coupled to the core tier. The outer-net tier participates on an ad hoc, usually short-term basis to provide specialized expertise for tasks that are often separable from on-going work. These tiers do not necessarily align with organizational hierarchy (Ancona et al., 2002).

This structure creates flexibility to adapt to changing external demands with centralized coordination and oversight and decentralized execution. The tiers are transparently overlaid on a typical organizational hierarchy; it does not change the reporting or management relationships, but it can help clarify roles and responsibilities.

Building upon a relatively clear understanding of organizational structure as the division of labor into distinct tasks and the coordination among these tasks (Child, 1977; Mintzberg, 1993), interorganizational structure is related to the way work is divided up by assigning specific roles to partnering organizations and establishing the way coordination is achieved among them (Kumar & van Dissel, 1996). Coordination includes protocols, tasks, and decision mechanisms to achieve concerted action between interdependent units (Scott, 1992; Thompson, 1967). Just as organizational structures have distinct properties, interorganizational structures have identifiable properties as well (Schopler, 1987; Sydow, 1997; Sydow & Windeler, 1998). Due to the prevalence of virtual enterprises and outsourcing leading to increasingly interwoven organizations (Larsson *et al.*, 1998), boundaries are becoming more permeable and work units have transformed from functional chimneys to cross-functional teams (Denison *et al.*, 1996).

Design of interorganizational structure provides opportunities and poses challenges for information sharing, organizational learning, and relationship building, among other things. "The principle of modularity is fundamental to the structuring of organizations to achieve communication efficiencies" (Grant, 1996, p. 381). This is especially true of interorganizational structures. Systems theorists (Glassman, 1973; Granovetter, 1973; Simon, 1969) have described the notion of modularity as the dense interconnections within subsystems and the loose linking relationships between subsystems. These loosely joined systems allow for maximum adaptive potential of the system since changes can be made in one subsystem without major disruption to the performance of other subsystems (Whetten, 1981).

In interorganizational structures that are loosely joined in the manner of highly modular systems, not all organizations have linking roles. The linking organizations have the role of integrating the entire set of organizations by providing communication channels and transferring resources (Whetten, 1981). For complex products, where organizational structure often mirrors product architecture (Galbraith, 2002), the integrating/linking organizations are also likely to be the product system integrators. Because of their integration role, these organizations become focal or hub organizations and, as a result, gain status, influence, and power in the network, often having a large influence on network effectiveness (Sydow &

Windeler, 1998; Whetten, 1981). This power is likely to manifest itself in several different ways. Power in social systems can be vertical and horizontal, as well as interpersonal or involving relations between organizations (Salancik & Pfeffer, 1974). The formal structure of the interorganizational network impacts the division of labor, coordination of tasks, information sharing and communication. The informal expandable structure of an enterprise impacts how effective the linking organization is as an integrator, how standardized the interfaces between organizations are, and the distribution of power and economic benefits among organizations.

It is not clear whether the expandable structure would align with organizational boundaries or not. It is possible to imagine the linking organizations (system integrators) and their strategic partners as the core tier, the operational tier largely made up of suppliers, and the outer-net tier consisting of the remaining stakeholders. On the other hand, it is possible to imagine that every organization in the enterprise would have membership in all three tiers of the structure. There is potentially a role for both of these structures, although the first is closer to the formal hierarchy among the organizations and the second is perhaps truer to the characteristic of X-teams.

Flexible Membership

Fluid membership between tiers in the expandable structure and onto and off of the X-team is the idea of *flexible membership*. Because the expandable structure is not constrained by organizational hierarchy, members may, and do, transfer between the three tiers of the structure (Ancona et al., 2002). For example, an effective way for the core tier to maintain the identity of the team is for core tier members to have significant experience with the team. If a member moves from the outer-net tier into the operational tier, and then further into the core tier, by the time they reach the core tier, they have a good understanding of the history and direction of the team. This transfer from one tier to another allows the team to maintain continuity as people move in and out.

At the enterprise level, the idea of flexible membership relies on how the expandable structure is defined. If the tiers of the expandable structure exist in every organization, flexible membership occurs within organizations at the individual level. In this case, the mechanics of membership are very similar to the team level. Alternatively, if the tiers of the expandable structure are organizational boundaries, flexible membership is at the organizational level, and the challenge is much different. In this case, flexible membership between tiers may rely on the transfer of knowledge between tiers instead of the transfer of organizations between tiers. This requires interorganizational learning.

Interorganizational learning is achieved either by transferring existing knowledge from one organization to another, or by creating new knowledge through interaction among the organizations (Larsson et al., 1998). First, in transferring knowledge, both the transparency and receptivity of the organizations involved is important. Transparency allows for knowledge to be disclosed and receptivity allows for knowledge to be absorbed or used collectively to generate new knowledge (Larsson et al., 1998). With regard to the creation of new knowledge through interaction between organizations, interorganizational learning is likely the result of sharing tacit knowledge through socialization (Nonaka, 1994).

Internal Mechanisms for Execution

Internal mechanisms for execution for X-teams include integrative meetings, transparent decision-making utilizing real-time data, and using scheduling tools to pace and coordinate the timing of work to balance the external and internal focus of the team (Ancona et al., 2002). Meetings ensure that the most recent information from the external activities is incorporated into decisions. Transparent decision-making keeps team members moving in the same direction by informing members of the reasoning behind decisions. Clear deadlines and keeping track of schedules and progress allows all team members to appropriately pace and coordinate their activities to integrate the team's work. Other work has shown that these types of mechanisms, group meetings, planning, formal information systems, and rules and regulations, have all been shown to reduce uncertainty in processing information which leads to improved execution of tasks (Daft & Lengel, 1986).

In enterprises, formal authority and coordination are established by contractual relationships between organizations. Much of the interorganizational network literature has focused on the efficiency of exchange across interfaces through formal contract mechanisms. For example, according to Milgrom and Roberts (1992), the efficiency and performance of exchange relationships are influenced by the parties' ability to minimize the costs associated with contracting. Contracting costs are often broadened to include all costs associated with transactions, i.e. search costs, contracting costs (including negotiating), monitoring costs, and enforcing costs (Dyer, 1997). Transaction cost economics as a school of thought focuses on economizing these contracting costs to gain efficiencies (Williamson, 1981). However, it is recognized that simply minimizing these transaction costs does not maximize the transaction value, especially since a focus on efficiency does not consider many of the "noncontractibles" such as innovation and responsiveness (Zajac & Olsen, 1993). Other literature has emphasized the importance of differentiating contract structure according to the relationship, depending on the risk of the interaction and the trust between parties (Ring & Van De Ven, 1992).

In addition to specific contract types, Thompson (1967) suggests that different coordination mechanisms are appropriate for different types of interdependence between organizations. Using March and Simon's (1958) typology of coordination mechanisms, pooled interdependence (both units contributing to the goal) requires coordination by standardization, sequential interdependence (one activity precedes another) requires coordination by plan, and reciprocal interdependence (activities are both inputs and outputs) requires coordination by mutual adjustment (Thompson, 1967). Because of the network nature of large programs, including multi-organization leadership and authority, coordination and communication mechanisms are essential for execution. In order to reduce transaction costs, and due to the diversity of organizations involved and diversity in the level of their involvement in the enterprise, there may be numerous contract types and coordination mechanisms in play at any one time.

Another important execution mechanism, at both the team and enterprise levels, is having explicit decision rules that enable transparent decision-making. Explicit decision rules avoid ambiguity and provide flexibility to evaluate changing circumstances (Ancona et al., 2002). The extent to which members share information affects how it is processed and how decisions are made (Gruenfeld et al., 1996). Arranging decisions so that they can be made based on information largely available to individuals is a way to deal with the bounds on human rationality (Simon, 1969). Accessible information and explicit decisions rules are tangled together as enablers of transparent decision-making and coordination in the enterprise. In an interorganizational network, having accessible information in the enterprise relies strongly on each organization being able to transfer knowledge effectively. In fact, those organizations able to transfer knowledge effectively are more productive and more likely to survive than those less adept at knowledge transfer (Argote *et al.*, 2000). Another benefit of accessible information and transparent decision-making is the clarity of purpose it provides for the enterprise. Attracting members' attention, energy, and resources towards the enterprise's mission as well as creating a supportive environment and distinct identity for the enterprise are important for execution (Yan & Louis, 1999).

Contextual Enablers and Interactions

In addition to the hallmark characteristics, four contextual factors were identified as enablers of high performance for X-teams. These factors are a mandated three-tier structure, the use of explicit decision rules, having accessible information, and a learning culture (Ancona et al., 2002). Enterprise context is different than team context because of the difference in scale. Factors that are contextual at the team level are internal to an enterprise. It should be apparent from the previous discussion that contextual enablers for X-teams become important parts of the enterprise-level characteristics. Programs do have their own context, external to their boundaries, but the particular contextual enablers for the enterprise-level characteristics are not clear. Common contextual enablers for the cases studied could not be identified. While many cases had similar characteristics, they had a wide variety of fairly specific contexts. This is one area that should be explored further with future work. Before, getting too far ahead, I turn now to a case study of the F/A-18E/F Super Hornet to explore these enterprise-level characteristics empirically.

F/A-18E/F Case Study

Previous research I completed as part of my Master's thesis (Stanke, 2001) involved case studies of four successful aircraft programs, including the Super Hornet. In particular, the F/A-18E/F program stood out because of their accomplishment of staying on schedule and within budget while delivering technical quality. This is an impressive feat for an eight-year, $4.88 billion (FY92 dollars) development effort, and the F/A-18E/F is an exemplary program in the aerospace industry. Although much larger than a product development team, the Super Hornet enterprise achievements are strikingly similar to the results exhibited by the X-teams. This insight led to a secondary analysis of the F/A-18E/F case study data to explore the similarities between X-teams and the Super Hornet enterprise. This analysis indicates promise for extending the X-team characteristics to the enterprise level to develop theory of high performance extended enterprises, but it also motivates further investigation since there are many issues at the enterprise level that are not well understood empirically.

Background

A full-scale development program for the Super Hornet began in 1992. The U.S. Navy understood the need for a development program to modernize their aircraft fleet. Initiation of the F/A-18E/F program followed shortly after the cancellation of the A-12 program (January 7, 1991), which was the largest contract termination in Department of Defense (DoD) history at the time (Pike, 2005). A review leading to A-12 cancellation revealed significant technical problems as well as major cost and schedule overruns (Pike, 2005). In the aftermath of the A-12 program cancellation, both the Navy and the U.S. government were concerned with the credibility of the development strategies and program management techniques that were standard practice in the industry at that time. At the time the A-12 was cancelled, it was the Navy's largest aircraft development effort; without the A-12, the future of Naval aviation rested on the Super Hornet. More to the point, the future of Naval aviation relied on revolutionary changes taking place with the way the Super Hornet was developed and managed (Stanke & Murman, 2002).

The Super Hornet was developed and integrated by Boeing (then McDonnell Douglas) as the prime contractor to the Navy customer. Boeing makes approximately two-thirds of the aircraft and integrates the final system. Northrop Grumman is the principal subcontractor on the program; they make the aft third of the aircraft including where the engines fit into the plane. GE and Raytheon are also key partners providing the engines and the radar respectively. Hundreds of suppliers provide additional parts and materials for the plane.

The F/A-18 aircraft family includes previous A/B and C/D versions. With the exception of 90 percent commonality in avionics and limited similarity to the C/D airframes, the E/F versions are significantly different than previous Hornets. The E/F planes are 25 percent larger, have a 40 percent increase in un-refueled range, 25 percent increase in payload, three times more bring-back ordnance (weight which can be landed with on an aircraft carrier), and five times greater survivability. It is not conventional to change the name of the aircraft with every new version, but because of the significant improvements over the C/D, the E/F was named the Super Hornet. So although the E/F was an upgrade to an existing platform, it was more like a new development in many regards.

In 1999, the Super Hornet successfully completed Operational Evaluation testing (OPEVAL) with the rating of "operationally effective and suitable," the highest rating achievable, meeting all of its pre-defined operational requirements. The program was never re-baselined and program goals set at the time of the contract award were met. The F/A-18E/F program received the Collier Trophy in 1999. These accomplishments, recognized by external sources, indicate the success of the program.

Data Collection and Analysis

Our case study was conducted in 2000 by a group of several researchers, led by the author, using a structured hybrid survey-interview tool for data collection. The focus of the case study was to identify practices and strategies that led to the program's success in delivering value to its customer over the lifecycle of the aircraft system. More than 80 interviews were conducted, documents were reviewed, and several program meetings were observed over the course of several months at three separate organizations: Boeing Northrop Grumman, and the Naval Air Systems Command, NAVAIR. Additionally, the interviewees represented a variety of functional areas and management levels.

The data from the F/A-18E/F study, along with three other cases[3], were presented at two conferences (Hallander & Stanke, 2001; Stanke & Murman, 2002) and as part of my Master's thesis (Stanke, 2001). The data from each case study were represented in the form of practices, each identified by multiple sources. Original analysis of these data included an ad hoc aggregation of the practices from all four cases together. Six themes emerged from this clustering, listed below (Stanke, 2001):

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[3] The Lockheed Martin F-16, the Boeing 777, and the Saab JAS 39 Gripen

- *Holistic Perspective:* view of the entire system and its entire lifecycle
- *Organizational Factors:* structural and cultural factors related to the organizations in the enterprise
- *Requirements and Metrics:* specification and allocation of system requirements and the metrics used to track performance to system (technical) and programmatic (cost and schedule) goals
- *Tools and Methods:* tools and methods used for system design, integration, communication, and program management
- *Enterprise Relationships:* working relationships between organizations in the enterprise
- *Leadership and Management:* "best" management strategies and practices to facilitate continuity through leadership transitions

To investigate the similarities of the F/A-18E/F case study with the X-teams theory, I returned to the raw data from the Super Hornet case and performed a secondary analysis. I coded the F/A-18E/F practices in terms of the X-team characteristics. By practices, I mean observable behaviors that I codified and vetted with the program as accurately characterizing the ways they operated as an enterprise and the ways they executed the program. For example, one of the practices in the requirements and metrics category was having a flow down and roll-up of requirements, metrics, and responsibility, authority, and accountability (RAA) throughout the enterprise. Another example was making decisions following the rule that the "airplane is the boss"; this meant that all stakeholders made decisions based on what was best for the airplane instead of what would optimize their individual interests.

Results

In general, the practices from the Super Hornet case study aligned well with the X-team characteristics. The alignment of the X-team characteristics compared to the six themes from the original analysis is shown in Table 1 below. The numbers at the intersections of each row and column indicates the number of practices represented by both the X-team characteristic and the theme. For example, in the first row, External Activity, there are two practices from the Leadership and Management category. One of those practices is leadership emphasis and insistence on developing and maintaining credibility of the program, in order to "keep the program sold" to the Department of Defense (DoD), Congress, and the general public. This practice is representative of the Leadership and Management category, but also aligns with the X-team characteristic of External Activity.

Table 1. Comparison of Original and Secondary Analysis of F/A-18E/F Practices

		Best Lifecycle Value Themes						
		Holistic Perspective	Organizational Factors	Requirements and Metrics	Tools and Methods	Enterprise Relationships	Leadership and Management	Total
X-Team Characteristics	External Activity	1			1	3	2	7
	Extensive Ties	1	1			1	1	4
	Expandable Structure	1	1	1		4		7
	Flexible Membership		1	1		1		3
	Internal Mechanisms for Execution	1	1	3		2	3	10
	Other (Internal Integration)	1	2		4		2	9
Total		5	6	5	5	11	8	40

Despite the different focus of the original study, there is strong indication that the X-team characteristics are representative of the F/A-18E/F program. It is not particularly important how the practices are distributed throughout the matrix, but the total number of practices aligning with each X-team characteristic is interesting. In total, of the forty practices in the F/A-18E/F case, more than three quarters of them aligned with the X-teams characteristics. Additionally, three of the five X-teams characteristics were represented by seven or more practices. This suggests at the enterprise level, at least in the Super Hornet case, external activity, expandable structure, and internal mechanisms for execution may be more significant characteristics. This alone is a new insight relative to the X-teams theory where all five characteristics were weighted equally in terms of contribution and importance to team performance.

There is substantial overlap between the practices observed in the Super Hornet case and the X-team characteristics, but to fully depict enterprise behaviors requires additional characteristics. As indicated in the table, there were also several practices identified which did not fit the X-team characteristics (9 of the 40). These practices were largely related to issues of internal integration of both the system and the enterprise. These issues go beyond the coordination addressed by internal mechanisms for execution at the team level. This suggests that the X-teams theory needs to be expanded to adequately describe program enterprises.

An enterprise-level theory has begun to emerge from the F/A-18E/F data; there are several aspects that are not fully understood. Specific reformulation of the X-team characteristics to adequately represent the enterprise level, additional characteristics required to fully explain high performance enterprises, and relationships between various characteristics all require additional empirical investigation and development.

Summary

The X-team characteristics of external activity, extensive ties, expandable structure, flexible membership, and internal mechanisms for execution were observed in a high performance program in the aerospace industry, the F/A-18E/F. Not all practices from the program were accounted for in these characteristics though. Large programs, like the Super Hornet, involve complex technical and social systems. This complexity likely accounts for the necessary expansion of the X-teams theory when applied at the enterprise level. The theory of high performing enterprises that is emerging from the F/A-18E/F case will be further developed with additional case studies and discussion throughout the remainder of this dissertation.

The contribution of this work will be development of an enterprise-level theory for high performance programs based on an application and extension of the X-teams theory. A desirable outcome of theory building research is "good theory (that is, parsimonious, testable, and logically coherent theory) which emerges at the end, not the beginning of the study" (Eisenhardt, 1989, p. 548). For the fields of engineering systems and organizational behavior, this research will provide a framework for increasing performance of large-scale engineering programs, as well as a better understanding of the interorganizational networks that make up enterprises. For the research sponsor, the Lean Aerospace Initiative, this work contributes to the body of knowledge being developed about high performance enterprises. This area also has practical applications. For program managers it will provide a scaffolding of characteristics and practices for high performance, success-oriented enterprises; for the corporate manager trying to balance several programs at once, it will provide a way to manage revenue streams and deliver value to their customers.

Chapter 2

Studying Enterprises in the Real World

Introduction

Before launching into an approach for developing an enterprise-level theory, it is appropriate to refine the question of interest: **what are the foundational mechanisms that distinguish high performance enterprises?** Enterprise performance can be thought of in terms of both effectiveness and efficiency. Effectiveness is largely related to the outcome of the program; efficiency is related to the utilization of resources to execute the program. Effectiveness includes more than just the desired system performance. A program may not be considered effective, even if it meets all the technical requirements, if it is not delivered in a timely fashion or it is too expensive to purchase. Effectiveness may also have a time dimension, i.e. the effectiveness of a system may change over time. For example, a system that is highly effective when it is first delivered may lose its effectiveness at some later point if it can no longer meet the changing requirements. All of these aspects play a role with respect to enterprise performance.

In order to make the key question tractable, I will narrow the focus of this study to programs in the aerospace industry. Programs are of particular interest because they are a main organizing unit and often represent the revenue streams for their firms since they are directly linked to customers. The aerospace industry is accessible through the research sponsors, the Lean

Aerospace Initiative (LAI)[4]. There are several advantages of a limited scope. First, a narrower focus provides the opportunity for more substantive depth. A focus on aerospace programs leverages and builds on my previous experience. As a researcher, it is important to understand the contributions my background will make to this work. Second, the results will have a clear line of applicability and impact. A deeper understanding of the fundamental characteristics of high performance programs can provide a way to move beyond readily observable best practice heuristics.

Research Design

This research is an exploratory study of the factors related to performance of aerospace programs. The study is essentially a benchmarking of contemporary program execution to gain additional insight into the phenomenon and begin to understand distinguishing factors. The goal of exploratory research is to generate theory and the hypotheses that compose it (Stebbins, 2001). Grounded theory is developed inductively from studying the phenomena represented. A key feature of grounded theory development is systematic and concurrent data collection, analysis, and theory development. A systematic process of discovery, such as grounded theory, leads to more accurate generalized findings than other methods of discovery, namely speculation, serendipity, or pooling a small number of scattered cases (Stebbins, 2001).

In grounded theory approaches, the starting point is an interesting question and an area of study, not a particular theory or hypothesis (Glaser & Strauss, 1967; Strauss & Corbin, 1990). The starting point for this work is the noted phenomenon that successful program execution is the exception in the aerospace industry. In fact, it is so rare for programs to meet all their

[4] The Lean Aerospace Initiative is a research consortium and learning community involving government, industry, and academia, focused on improving performance of aerospace enterprises. More information about the consortium is available at http://lean.mit.edu.

performance goals that many are deemed successful in spite of some goal shortfalls. The type of program success of interest is the high performance, exceptional success that has been noted in a small number of instances, such as the F/A-18E/F.

Case Selection

Case study methods are appropriate given the exploratory nature of this work (Robson, 2002). The structure of case studies facilitates collection of a rich description within a limited time frame. Additionally, case studies are a preferred method for examining contemporary events in which the relevant behaviors cannot be manipulated (Yin, 2003).

In order to identify characteristics that distinguish high performance enterprises, a range of programs was investigated. The programs were selected primarily based on pragmatic concerns such as accessibility, but an attempt was made to represent a spectrum of programs across many different dimensions. These dimensions are shown in Table 2 along with their categories.

Table 2. Program Dimensions and Categories

Dimension	Categories
Program Success	Best in class, Successful, Mixed record, Not on track
Program Lifecycle	Concept development, Detailed design and testing, Production, Operation and support
Industry Sector	Military aircraft, Commercial aircraft, Spacecraft (launch vehicles and satellites), Electronics and avionics, Engines, Missiles
Customer	U.S. government, International government, Commercial
Production Volume	Orders of magnitude (1's, 10's, 100's, 1000's)
Company	n/a
Size	Small, Medium, Large
Technology Risk	Low, Medium, High

The full scale of all dimensions is represented by at least one of the cases in this study with one exception. Along the industry sector dimension, no commercial aircraft cases were conducted due to access and timing issues, although cases using commercial practices were included. Because program performance is central to this research, it is also interesting to look at the range of programs studied based on their demonstrated record. This distribution is illustrated in Figure 2.

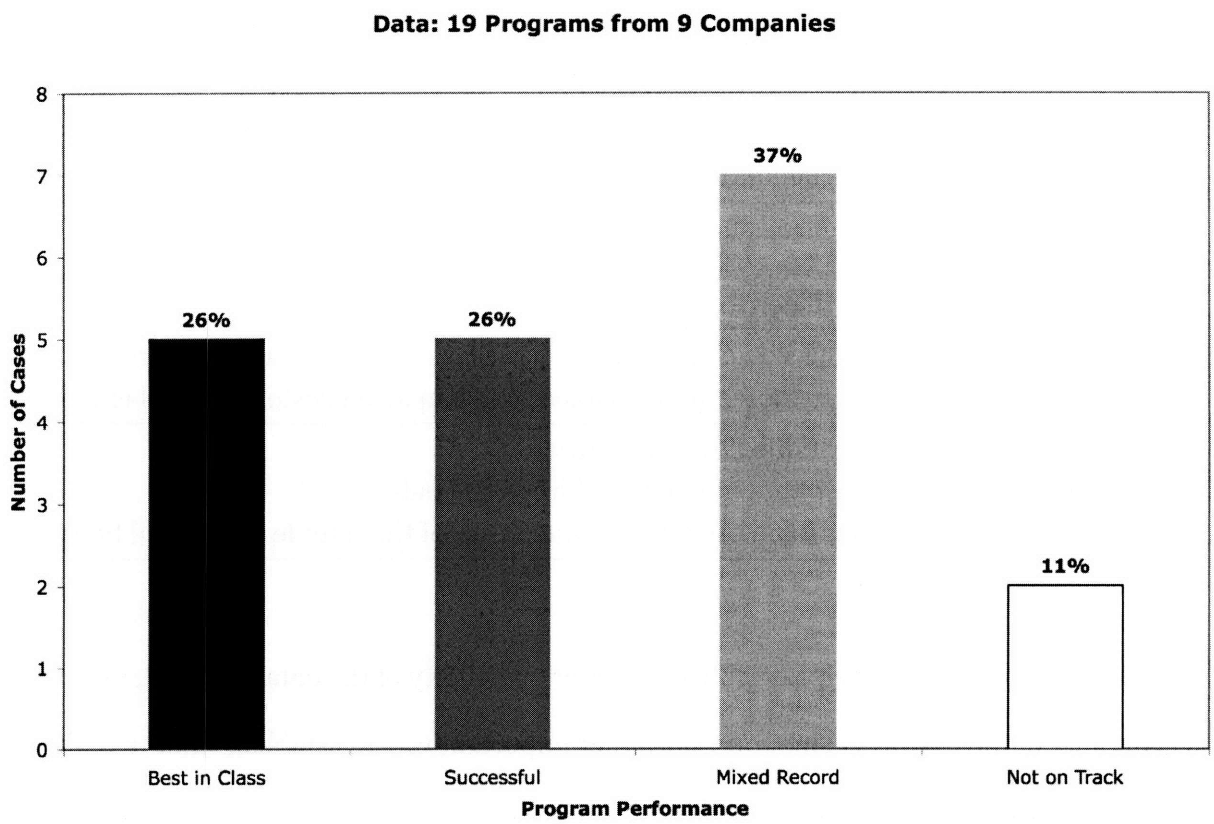

Figure 2. Sample of Programs Based on Record

This is a personal, subjective assessment of program performance, and it is not meant as any rigorous evaluation of any of the cases studied. It is only presented to depict the variety of cases studied. The evaluation is based on extensive research into each program, including documented evidence (both critiques and accolades), interviews with program personnel and external industry experts (retired executives, a retired engineering manager, a retired Air Force

General, and a current industry analyst), and comparison between programs in the sample. Basic criteria, outlined in Table 3, were followed as consistently as possible; programs in each category met all of the criteria listed.

Table 3. Program Evaluation Criteria

Rating	Criteria
Best in Class	• Highly praised by third parties (popular media, program evaluators, industry experts, etc.) • Evidence of sustained performance over time (including through leadership transitions) • No other programs in the sample performed as well • No required changes to loosen performance goals (technical requirements, cost, or schedule) in order to meet them
Successful	• Acknowledged success in many regards • Changes to loosen performance goals did not impair customer satisfaction (e.g. slip in delivery date or increase in cost)
Mixed Record	• Program faced acknowledged challenges that could not be overcome • Changes to loosen performance goals impacted customer satisfaction
Not on Track	• Highly critiqued by third parties • Evidence of not meeting performance goals • Programs in all other rating categories of the sample performed better

The variety of cases studied helps establish the external validity of the data collected, indicating the generality of the findings (Yin, 2003). Another important way to establish validity in this type of research is to gather sufficient observations to reach "saturation" (Stebbins, 2001). Saturation is reached when no new insights are being made from subsequent work. This notion is important in determining both the number of cases to study and the number of interviews to conduct. The number of cases and interviews can be estimated before the work begins, but cannot be determined until the work is underway.

In the end, in addition to the in-depth F/A-18E/F case, 19 cases (including a return to the F/A-18E/F) were developed from 9 different companies. These cases were initially based on responses to the research proposal but, towards the end of the work, cases were selected to ensure broad and representative coverage of the industry. Typically, an organization would agree to participate and I would work with a local point of contact to select the specific programs. This contact was not always involved with the program studied, but they provided entry to the organization and always helped to select interviewees and coordinate the site visits. Seventeen cases were conducted on-site at the host organization; when this was not possible, program personnel were interviewed at a mutually convenient location. All case data were collected between June 2005 and January 2006.

Interview Selection

Aerospace programs generally have a value stream from supply chain to major subsystem integrator to prime system integrator to acquirer to end user. The focus of these cases was at the prime system or major subsystem integration level. From this middle perspective, relationships upstream and downstream within the program to the customers and suppliers could be explored. Relationships outside of the program with the corporation and the environment could also be investigated. Interviewees were selected only from these organizations, even though it is acknowledged that they do not represent the entire enterprise.

In setting up each case study, I requested to interview three individuals from each program. I relied on my local contacts to navigate the programs and identify the interviewees. I provided the following suggestions for candidates: chief engineer, lead systems engineer, program manager, deputy program manager, and customer or supplier liaisons. These candidate positions were targeted with the intention of interviewing people who have a broad view of the program and some sense of its history. Based on availability constraints, the number of interviews varied across cases. Between one and seven interviews were conducted for each program, with a total of 53 interviews across the 19 cases. In every case except one, the program manager or deputy was interviewed and in every case the chief engineer was interviewed. Fifty of the interviews were conducted in person. When this was not possible, a phone interview was conducted.

Data Collection

A research protocol, including interview questions, was used to help strengthen the reliability of the findings (Yin, 2003). The research protocol is included in Appendix B – Research Protocol. This protocol provided a common starting point for all interviews, introducing the topic and the questions to the interviewee. The questions outlined in the protocol were guidelines for the interviews, but each interview took a unique form, following the flow of dialogue between the interviewee and myself. The exact questions from each interview were highly tailored based on the context of the interview and the discussion as it unfolded.

Various types of questions were used to elicit and organize information. Descriptive questions about relevant experiences or examples were used to help explain the program and program execution strategies. Structural questions about the organization of the program, the number of suppliers, the types of interactions between customers, suppliers, and other programs in the same company were used to help organize information. The majority of the interviewees had many years (10 or more) of experience with a variety of programs. In these interviews, contrast questions were sometimes used to compare the program of interest to other programs familiar to the interviewee. This helped clarify and develop the meaning of information collected. Descriptive, structural, and contrast questions are complementary ways of gathering and organizing information during an interview (Spradley, 1979).

Developing a sense of openness and trust between the interviewee and myself was critical to collecting data for these case studies. At the beginning of each interview, I introduced myself to the interviewee, including my educational background and how I became interested in this topic. This allowed me to build rapport with the interviewees. Often, they could relate to me because of my background in mechanical engineering. It was also useful to share with the interviewees that I have spent the past five years working with the LAI at MIT. This has provided me the opportunity to work with many organizations (companies and government) within the aerospace industry on a variety of projects. Although I have always worked with these organizations as an outsider, I have gained substantial knowledge about the organizations and the industry, which helped me understand the interviewees' comments. In some cases, the interviewee and I already knew each other or had mutual acquaintances, which also helped develop a friendly rapport for the conversation. I also asked each interviewee to begin by telling me a little bit about their background. This helped me understand a framing perspective for their comments. My research sponsor, the LAI consortium, has an established reputation as a learning forum and MIT, as the academic participant in this consortium, plays the role of neutral broker among competitors, customers, and suppliers in the aerospace industry. The endorsement and support from LAI and MIT also helped to establish trust between the interviewee and myself. Personal rapport and the reputation of my research sponsors were the key factors in creating an open and trusting environment for each interview.

Due to security policies at the organizations visited, the interviews were not tape-recorded. Data were collected in the form of notes taken by hand during the interviews. Observations and recollections were added to the notes as soon after the completion of the interview as was practical. The notes and observations were subsequently typed and compiled for each case. Although not as complete as a transcription of the interview, the process of taking notes, reviewing them to add detail, and then typing them created as complete set of data as was possible. Data were also collected from review of publicly available documents about each program. This available information was combined with the interview notes to write a case study report for each case that was reviewed by the host organization and the interviewees to ensure that the information was captured accurately. This iterative review of the data allowed me to become deeply familiar with the findings of each case individually. This is important in a multi-case study where generalizations are made from patterns that emerge from cross-case analysis (Eisenhardt, 1989).

Using a research protocol, developing rapport with each interviewee at the outset of the interview, and thorough and repeated review of the data collected were all important aspects of the data collection process for this study. These techniques combined to ensure that the data are reliable, complete, and accurate, which are realistic concerns with any qualitative study.

Limitations

With any research method there are limitations on the data that can be collected and the findings that result. This study is no different, and it is important to understand the limitations before considering the data and conclusions. One limitation relates to the cases selected to include in the study. By not including any commercial aircraft cases, a significant sector in the industry was neglected. I have argued that the practices used by these programs would not be substantially different from the cases studied, but without any representation of the sector, this is hard to prove. Additionally, in many regards, the cases range from typical to exceptional examples from the industry. Collectively they are a fairly representative sample of the industry, but the demographics of the sample do not mirror the demographics of the industry. Another limitation of the study is related to the number of interviews conducted for each case. Only one in-depth case study was conducted with a large number of interviewees. In some cases (three), only one individual could be interviewed. In these cases, the local point of contact, a follow-up interview with the individual, or publicly available material was relied upon as a data source. This is certainly not ideal, but it is the reality of doing research that requires access to organizations by an outsider. In addition to limitations on data sources (cases or interviews), there are also limitations on the data collection techniques, in this case, interviews. A viable critique of semi-structured and open interviews is that every interview takes on a unique flavor based on the interaction and dialogue between the researcher and the interviewee. Although a research protocol, with a set of questions, was used for all interviews, the flow of conversation was highly variable between interviews and, as a result, different data was collected in each interview (both in quantity and quality). Lastly, there are obvious limitations with this work in restricting the study to programs in the aerospace industry. The findings may be relevant to a large class of interorganizational networks across many industries, but this study does not include any evidence to support that proposition.

Summary

This study of the distinguishing attributes of high performance enterprises is set up as an exploratory study of aerospace programs. Using a comparative case study, grounded theory approach allows a rich understanding of the phenomenon without requiring a controlled experimental environment. The focused scope of this work builds on my strengths as a researcher. The cases selected provide adequate coverage of the aerospace industry in a number of dimensions to ensure the findings will be valid and extensible. Nineteen cases were required to reach data saturation and achieve this breadth. Data saturation was determined by the stability of emergent themes and categories, resulting from concurrent coding and analysis of the data, which will be discussed in Chapter 4. These 19 cases represent a spectrum of enterprise performance. In each program, a small group of interviewees was carefully selected and interviewed following a research protocol. Data collection involved an iterative process of compilation, review, and supplementing original interview notes, until a complete set of data was stabilized. Qualitative methods are often critiqued in the social sciences for the lack of rigor. It is essential in every scientific endeavor, but particularly in an empirical study based on qualitative data, that every precaution was taken in selecting the sample and in conducting the research procedures to ensure the integrity of the data.

Chapter 3

Aerospace Program Case Studies

Introduction

The following summaries are provided as an introduction for the cases studied. More detailed descriptions of the case studies are available in Appendix C – Aerospace Case Studies. This summary is meant to give the reader a first hand appreciation for the variety of cases studied. Although many of these programs have long histories, often the study was limited to a relevant time period. For example, the early years of several programs were not included because they pre-date contemporary program management practices. The organizations involved in this research were gracious and open in sharing their experiences for the benefit of this research; any errors or inadequacies in representing it are entirely my own.

To introduce the cases, a description of the typical structure and timeline of an aerospace program may be helpful. As mentioned previously, the aerospace value stream extends from suppliers through end users. Programs generally have two types of customers: acquirers and end users. The acquirer is often an active participant in a program enterprise, while the end user generally is not. In the case study descriptions, references to the customer generally refer to the acquirer. The systems are developed and produced by a system integrator or prime contractor and their partners and suppliers. In many cases, the system integrator will have a closer relationship with a few key partners, usually major subsystem integrators. These relationships are generally characterized by some distribution of risk and reward across the organizations. Returning to the F/A-18E/F, Boeing as the system integrator works closely with Northrop Grumman, who makes the aft section of the airframe, GE, the engine supplier, and Raytheon, the radar supplier. Northrop Grumman, GE, and Raytheon are partners to Boeing for the Super Hornet program. To confuse things further, sometimes the acquirer works directly with some suppliers to develop and purchase some important subsystems. These suppliers still have to remain in close coordination with the system integrator (who usually installs the subsystems), but the contractual relationship, development of requirements, and exchange of money may happen directly with the acquirer. For the F/A-18E/F, both the engines and the radar fall into this category. The Navy buys them directly from GE and Raytheon, but Boeing integrates them into the airframe. In the case of the engines, GE works closely with Boeing who installs them, but also with Northrop Grumman who developed and produced the aft section of the airframe where the engines are installed. These sorts of relationships are complicated, but they are fairly typical of aerospace programs.

Development and production of aerospace systems falls under several different names, but generally follows a basic sequence, similar to that laid out in many product development texts. As shown in Figure 3 below, the first phase is concept exploration, then system-level design, detailed design, testing, low rate production, and finally full rate production.

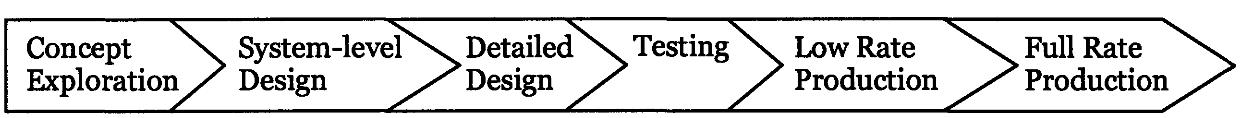

Figure 3. General Aerospace Product Development Phases (adapted from Ulrich & Eppinger, 1995)

Once a program reaches full rate production, systems are being delivered for operation. At this point, the whole development sequence may start over for modifications or variants of the system. It is not unusual for a program to have concept exploration, high-level or detailed design, testing and production all occurring simultaneously for various versions of the system. Again, to return to a concrete example for reference, on the Super Hornet program, when the E/F was in low rate production, a major redesign to the forward fuselage and cockpit was in system-level and detailed design.

Data Summary

The 19 cases studied represent a wide range of aerospace programs. But in many ways, the sample of cases studied is not like the industry as a whole. For instance, not all sectors of the industry are represented. No launch vehicle (rocket) or commercial aircraft programs were studied. Of the sectors that were studied, the number of programs in the sample is not descriptive of the industry. The electronics/avionics sector has many more programs than the aircraft or spacecraft sectors, but the numbers of cases from those sectors do not reflect that. Only one engine program was studied, even though there is roughly the same number of engine and aircraft programs. Additionally, while the spectrum of program performance illustrated by the cases is representative of the industry, the distribution of programs along this spectrum may not be typical. In fact, the sample includes the many of "best in class" programs in the industry, but it only includes a couple of programs struggling with success. It is worth reiterating here that the programs studied were selected based on a number of factors, including how typical the case is, recommendation of local points of contact in the companies studied, recommendation of industry experts, and accessibility issues. That being said, the cases provide adequate treatment of the aerospace industry by covering a broad scope of program characteristics. The following tables will introduce the cases and illustrate this coverage by summarizing several various aspects of each program.

Table 4 through Table 7 provides a concise description of the 19 cases studied, highlighting some basic facts and attributes of each program. Table 4 identifies the data sources used for the case; in all cases, in addition to the interviews listed, publicly available documents and documents shared by the interviewees were also used as data sources. Table 5 covers the timelines for each program, Table 6 covers the organizations studied, their roles, and the major stakeholders for each program, and Table 7 provides some general characteristics such as program size and product capability. Together the tables give a good flavor of the variety of the programs studied. Following the tables, rather than cover all cases in-depth, the F119 case is provided as an example, and extended summaries of the remaining cases can be found in Appendix C – Aerospace Case Studies. I have selected the F119 case as the example here because the challenges it faces are fairly typical of the industry, and the F119 enterprise has been notably successful. It also provides a good comparison to the F/A-18E/F and other examples cited throughout the thesis.

Table 4. Case Study Summary – Data Sources

Sector	Program	Date Conducted	Number of Interviews	Program Roles Interviewed
Aircraft & Engines	C-17 Globemaster III	8/2/05	4	Program Management, Systems Engineering, Chief Engineer, Supply Chain Management
	F119 (F/A-22 Engine)	10/21/05	4	Program Management, Systems Engineering, Manufacturing Liaison
	F-16E/F Desert Falcon	7/6/05	3	Program Management, Business Management, Systems Engineering
	F/A-18E/F Super Hornet	6/00 - 8/00	81	All major contributing functions at multiple levels across three organizations
		8/22/05	2	Chief Engineer, Systems Engineering
	SilentEyes™	6/1/05	2	Program Management, Chief Engineer
	X-35 (JSF Proposal)	7/7/05	3	Program Management, Chief Engineer, Supply Chain Management
Electronics/Avionics	F-16 Radar (AN/APG-68(V))	9/15/05	1	Program Management
	F/A-22 Radar (AN/APG-77)	9/15/05	2	Program Management, Systems Engineering
	Joint Tactical Radio System (JTRS) Ground Mobile Radio (GMR)	8/16/05	3	Program Management, Business Management, Supply Chain Management
	JTRS Handheld Manpack Small Form Fit (HMS)	8/16/05	2	Program Management, Systems Engineering
	JTRS Airborne Maritime Fixed (AMF)	8/17/05	2	Program Management, Chief Engineer
Munitions	Case A*	6/29/05 7/25/05	7	Program Management, Chief Engineer, Systems Management, Customer Chief Engineer, Supply Chain Management
	Exoatmospheric Kill Vehicle (EKV)	6/29/05	3	Program Management, Systems Engineering, Chief Engineer
	Joint Direct Attack Munition (JDAM)	8/23/05	4	Program Management, Systems Engineering, Chief Engineer, Supply Chain Management
	Sensor Fuzed Weapon (SFW)	6/21/05	3	Program Management, Chief Engineer, Supply Chain Management
	Standard Missile 3 (SM-3)	6/1/05	4	Program Management, Systems Engineering, Chief Engineer, Supply Chain Management
Spacecraft	Global Positioning System (GPS) IIF	8/1/05	1	Program Management
	Globalstar	11/18/05 1/17/06	2	Program Management, Chief Engineer
	Iridium	11/1/05 3/7/06	1	Chief Technical Officer

* Identification of this case is not possible at the time of publishing.

Table 5. Case Study Summary - Timelines

	Program	Timeframe Studied	Program Phases Covered
Aircraft & Engines	C-17	1994 – present	Low rate production -> operation
	F119	1991 – present	System-level design -> operation
	F-16E/F	2000 – present	Detailed design -> operation
	F/A-18E/F	1992 – present	System-level design -> operation
	SilentEyes™	1999 – 2004	Concept exploration -> testing
	X-35	1996 – 2001	Concept exploration -> system-level design
Electronics/Avionics	F-16 Radar	1995 – present	Detailed design -> operation
	F/A-22 Radar	1991 – present	System-level design -> operation
	JTRS GMR	2002 – present	System-level design -> detailed design
	JTRS HMS	2005 – present	System-level design -> detailed design
	JTRS AMF	2003 – present	Concept exploration -> system-level design
Munitions	Case A	1997 – present	Detailed design -> operation
	EKV	1998 – present	System-level design -> testing
	JDAM	1995 – present	System-level design -> operation
	SFW	1982 – present	System-level design -> operation
	SM-3	1996 – present	System-level design -> operation
Spacecraft	GPS IIF	1996 – present	Detailed design -> full rate production
	Globalstar	1991 – 2000	Concept exploration -> operation
	Iridium	1989 – 1999	Concept exploration -> operation

Table 6. Case Study Summary – Organizational Roles and Major Stakeholders

	Program	Organization Studied	Location	Program Role
Aircraft & Engines	C-17	Boeing Integrated Defense Systems (IDS)	Long Beach, CA	Prime Contractor
	F119	Pratt & Whitney	Hartford, CT	Prime Contractor & Major Subsystem integrator
	F-16E/F	Lockheed Martin Aeronautics	Fort Worth, TX	Prime Contractor
	F/A-18E/F	Boeing IDS	St. Louis, MO	Prime Contractor
	SilentEyes™	Raytheon iFuzion	Tucson, AZ	System Integrator
	X-35	Lockheed Martin Aeronautics	Fort Worth, TX	Lead Partner
Electronics/Avionics	F-16 Radar	Northrop Grumman Electronic Systems Sector (ESS)	Baltimore, MD	Prime contractor & Major subsystem integrator
	F/A-122 Radar	Northrop Grumman ESS	Baltimore, MD	Lead partner & Major subsystem integrator
	JTRS GMR	Rockwell Collins	Cedar Rapids, IA	Major subcontractor
	JTRS HMS	Rockwell Collins	Cedar Rapids, IA	Major subcontractor
	JTRS AMF	Rockwell Collins	Cedar Rapids, IA	Major partner
Munitions	Case A	Raytheon Missile Systems	Tucson, AZ	Prime Contractor
	EKV	Raytheon Missile Systems	Tucson, AZ	Prime Contractor & Major subsystem integrator
	JDAM	Boeing IDS	St. Charles, MO	Prime Contractor
	SFW	Textron Systems	Wilmington, MA	Prime Contractor
	SM-3	Raytheon Missile Systems	Tucson, AZ	Prime Contractor
Spacecraft	GPS IIF	Boeing IDS	Huntington Beach, CA	Prime Contractor
	Globalstar	Space Systems/Loral and Globalstar LP	Palo Alto, CA	System Integrator
	Iridium	Motorola Satellite Communications	Chandler, AZ	System Integrator

Table 6. Continued

Customers	Major Partners/ Suppliers	Program Structure
U.S. Air Force (USAF)	Pratt & Whitney, Honeywell	Acquirer–Prime–Subcontractors (Subs)
USAF, Lockheed Martin Aeronautics		Acquirer–Prime–Subs
United Arab Emirates (UAE)	GE, Northrop Grumman ESS	Commercial contract
U.S. Navy (USN)	Northrop Grumman Integrated Systems Sector (ISS), Raytheon, GE	Acquirer–Prime–Principle Subcontractor–Subs
USAF		Integrator–Suppliers
USAF, USN, U.S. Marine Corp (USMC),U.K. Royal Air Force (RAF)	Northrop Grumman ISS, BAE Systems, Pratt & Whitney, Rolls-Royce, Northrop Grumman ESS	Joint Acquirer–Partnership–Subs
USAF, Foreign customers		Acquirer–Prime–Subs
USAF	Raytheon IDS, Boeing IDS	Acquirer–Joint Venture–Subs
U.S. Army	Boeing IDS	Acquirer–Prime–Competing Subs
U.S. Army	General Dynamics	Acquirer–Prime–Competing Subs
USAF, USN	Boeing IDS	Acquirer–Competing Teams
USN, USAF		Joint Acquirer–Prime–Subs
Missile Defense Agency (MDA)	Boeing IDS, Lockheed Martin Astronautics, Orbital Sciences	Acquirer–Prime–Subs
USAF, USN		Joint Acquirer–Prime–Subs
USAF		Acquirer–Prime–Subs
USN, MDA		Acquirer–Prime–Subs
USAF, Commercial	Lockheed Martin	Acquirer–Prime–Subs
Commercial	Qualcomm	Limited Partnership
Commercial	Lockheed Martin, Raytheon	Integrator–Suppliers

Table 7. Case Study Summary – General Characterization

	Program	Size	Product Capability
Aircraft & Engines	C-17	Large (1000s)	Large cargo aircraft for airlift capability
	F119	Med (100s)	Fighter engine providing supercruise (ability to go faster than Mach 1 without afterburners) and thrust vectoring and relatively low radar signature
	F-16E/F	Med	Fighter aircraft with enhanced engines, radar, and other avionics
	F/A-18E/F	Large	Carrier based fighter and attack aircraft; newest in the Navy's inventory; on-going development for an electronic warfare version
	SilentEyes ™	Small (10s)	Shoebox sized UAV for reconnaissance launched from larger UAV
	X-35	Med	Fighter aircraft with three variants based off a common platform: (1) land-based conventional version, (2) carrier variant, (3) short take-off and vertical landing (STOVL) version
Electronics/Avionics	F-16 Radar	Med	Radar for fighter aircraft; part of a modular avionics architecture
	F/A-22 Radar	Med	Active Electronically Scanned Array (AESA) radar for fighter aircraft; part of an integral avionics architecture
	JTRS GMR	Med	Software defined radio system covering broad range of frequencies for a wide variety of applications; this program develops most of the technology and software for the system
	JTRS HMS	Med	Uses technology from GMR for application in sensors, unmanned vehicles, munitions, handheld radios, and manpacks
	JTRS AMF	Small	Uses technology from GMF for integration with over 150 different airborne, maritime, and large fixed platforms
Munitions	Case A	Med	Short-range, launch and leave, air combat missile providing high off-boresight target acquisition
	EKV	Med	Kinetic kill vehicle integrated on the Ground Based Interceptor (GBI) for long-range interception of ballistic missiles
	JDAM	Med	Guidance tail kit that is attached to standard "dumb" bombs; family of four variants: two 2,000 lb, a 1,000 lb, and a 500 lb versions
	SFW	Small	Air-to-ground smart munition consisting of 40 warheads per weapon; can hit multiple moving or stationary targets with each launch; includes self-destruct mode to minimize collateral damage
	SM-3	Large	Three-stage rocket including a kinetic warhead for hit-to-kill interception of short to medium range ballistic missiles
Spacecraft	GPS IIF	Med	Fourth generation of the GPS system; replenishment satellites for the existing constellation providing enhanced capability
	Globalstar	Large	Constellation of satellites providing voice and data communications in conjunction with land-based gateways and existing cellular phone networks to handheld phone units for commercial customers
	Iridium	Large	Constellation of satellites providing voice and data communications in conjunction with land-based gateways to handheld phone units for commercial and military customers

Table 7. Continued

Production Volume	Basic Overview
180	Large program with long history, was almost canceled due to poor performance in the mid-90s; mature technology; unique sustainment partnership
423	Followed new development strategy at Pratt & Whitney, was important new program for their business strategy; engine has been launch pad for subsequent F-35 engine; significant new technology; unique sustainment partnership
80	Leverages very mature aircraft with over 4,000 units produced; added significant capability with the most significant change implemented in at one time to the platform; unique commercial contract for a foreign customer
432	Practically new development building from the design of previous Hornet aircraft; completely revamped existing Hornet enterprise relationships and management practices to change the way Super Hornet program was executed
Prototype/ Test Vehicles	Small research & development (R&D) effort; had some initial interest, but has not found a customer
2	Largest fighter competition in history; involved complex stakeholder relationships and difficult technical challenges
>6,500	Long history with many versions developed and many units in operation
>200	Integration challenges because of highly integral avionics architecture; spiral development including enhancements in each new version
~180,000	Many technical challenges; two redundant subcontractors working together throughout development, then they will compete for production contract; program has important potential for all stakeholders
	Highly interdependent with GMR program; uses competing subcontractor structure
	Large integration challenge with 100+ different platforms; numerous different stakeholders
~10,000	Important new technology development for company; provided important capability in an area where the US had been inferior to other country's technology
25	Hard technical challenges; as a major subsystem, program is highly interdependent on other system components (even for testing); challenges and failures in other components have negatively affected this program
>150,000	Low technical risk, suppliers tightly involved in all aspects, from development through production; highly efficient production line; has incorporated numerous new applications and developments; personal development opportunities used to keep key individuals involved with the program
5,000	Stable, mature program with long history; steady-state production affected mostly by supplier and material issues
11 in Block I	Spiral development program with several blocks in development or production at any one time; collaborative research effort with Japan to explore some new technologies
12	Follow-on development program to enhance the capabilities of the GPS satellite constellation when the current satellites are replenished; predicted production rates have decreased with the extended life of the current constellation; program includes not only development but also operation of the system
at least 52	Development of satellite system was dependent on other partners; international partnership to develop political capital; market did not develop as anticipated and company went bankrupt; currently in operation
100	Impressive production and delivery records; technical success but business failure (bankruptcy) when market did not develop as quickly as anticipated to recoup development costs; significant international partnering to develop political capital

F119 Engine for the F/A-22 (1991-present) Pratt & Whitney, East Hartford, CT

The newest fighter in operation for the U.S. Air Force, the F/A-22 Raptor, is powered by two F119 engines provided by Pratt & Whitney. These engines provide capabilities significantly above and beyond legacy fighters. Each F119 provides 35,000 pounds of thrust. For comparison, the F-15 or F-16 engines range between 23,000 and 29,000 pounds of thrust each (f22fighter.com, 2000). The F119 also has supercruise capability, or the ability to reach supersonic speeds without using afterburners. This provides the aircraft a larger operating range and is also stealthier. Despite having these additional capabilities, the F119 has 40 percent fewer parts than legacy fighter engines.

Additionally, the F119 is the first fighter engine to use hollow fan blades, which reduces the weight of the engine and increases responsiveness (Hehs, 2003a). Other revolutionary design features of the F119 include, overall modular design based on an integrated product design strategy, a single stage turbine, not only hollow, but integral fan blades, a vectoring nozzle, and low observables technology. Pratt & Whitney is currently scheduled to deliver more 423 engines, 358 to put into service plus 65 spares.

Program History

The F119 program originated as a prototype development for the Advanced Tactical Fighter (ATF) competition in 1986 (GlobalSecurity.org, 2005a). In April 1991, the Pratt & Whitney F119 was selected over the General Electric competitor to power the F/A-22 aircraft. The Engineering and Manufacturing Development (EMD) contract was awarded in December of that same year. Initial ground testing began in late 1992. Nearly four years later, in October of 1996, the first two flight test engines were delivered to Lockheed Martin for integration with the first airframe. The first flight occurred in 1997. Low Rate Initial Production (LRIP) began in 2001 (Pratt & Whitney, 2005). The 100^{th} engine delivery occurred at the end of 2003, and by the end of the

LRIP phase, 128 engines had been delivered. The first base to receive operational F/A-22 aircraft activated the first squadron in early 2003 (Pratt & Whitney, 2005). Full rate production began in early 2005 and is expected to continue into 2010.

Program Execution

From the beginning, the F119 program has been focused on teaming. In fact as one person on the program commented, *"customer and contractor are relatively new terms on this program, they weren't used for the first 12-13 years."* The early leadership at Pratt & Whitney and the Air Force established a team-based environment that is still prevalent today, over a decade and many subsequent leaders later. Supporting this, Pratt & Whitney has a strong customer focus; they constantly work on the partnership with their customer as a means to improving problem solving on the program. This customer focus can be seen with Lockheed Martin as well as the Air Force. Lockheed Martin integrates the engine with the airframe and, although they are not a formal customer for Pratt & Whitney (the Air Force buys the engine directly), Pratt considers them a customer and works closely to ensure they have the support they need. Pratt & Whitney have taken this partnership focus one step further to partner on the sustainment side with the Air Force Air Logistics Center for maintenance of the engines in service.

Because the F119 was developed during a time when the idea of "Acquisition Reform" was popular in the Air Force, the program had the opportunity to do things differently than previous programs. From the outset, the organizational structure at Pratt & Whitney and the Air Force were aligned to mirror each other, providing accessible counterparts at all levels of the organizations. Pratt & Whitney maintains given configuration control over the system. This means taking on more risk, but it also means having the potential to control costs more closely. With configuration control at the system integrator level, the Air Force customer had to specify performance based requirements. To ensure they could meet these requirements, Pratt worked closely with their suppliers, promoting the team-based culture further into the enterprise. Pratt

& Whitney also focused on their internal operations. They evolved their internal organizational structure, their business practices, and their business strategy simultaneously. This evolution was key to enabling the sorts of relationships and practices that were established and now have been sustained on the F119 program. In fact, as one participant remarked, *"Everything is evolving, and we're evolving now better than ever."*

Another hallmark of this program is open information sharing. Although Pratt has design authority for the system, they invite their customer to participate in the decision process on the program. Pratt & Whitney share their cost information with the Air Force, and the Air Force shares their budget information with Pratt. This makes negotiations more of a formality than anything else and ensures that everyone is focused on delivering the best system possible with the resources available.

Summary

The 19 cases studied represent a broad sampling of the aerospace industry. They differ along many dimensions, but together they provide a representative sample of contemporary aerospace program execution. The cases span timeframes from 1982 through the present. They include all aspects of a system lifecycle from concept exploration through operation. They include numerous organizations in the aerospace industry. They range in size from tens of people to thousands of people. They span production volumes from single digits to hundreds of thousands. They represent a wide variety of system capabilities. And, they have a broad spectrum of challenges and accomplishments. Interviews with a few key individuals and document review were the data sources for each case, and the F119 case description provides an illustrative example of the data collected. Cumulatively, the data from the cases are a comparative source of information about program execution approaches.

Chapter 4

Benchmarking of Aerospace Program Execution Strategies

Introduction

The case study analysis looked first within cases to identify themes, then across cases to identify patterns that led to categories. Data analysis began by summarizing the three or four unique themes from each case. These themes were identified by sorting through the interview notes from the case, weeding out key information from the supporting dialogue. The themes represent information that was repeated and emphasized throughout the interviews in the case. Where possible, the themes have been constructed by triangulating between multiple interviews in each case. In addition the interviewees, the point of contact for the host organization was also a source of information in some cases, which could also be used to help triangulate the data. The themes identified are an aggregation of the data for each case. This aggregation was done on a continual basis and, as more cases were conducted, patterns of themes across cases began to emerge. These categories of themes were reviewed, refined, and updated as more data were collected. This is standard practice in qualitative data analysis. Qualitative methods are particularly appropriate for isolating and defining categories during the process of research (Glaser & Strauss, 1967; McCracken, 1988). Qualitative methods are also appropriate for capturing complexity when there are interesting patterns of interrelationships between categories as opposed to sharply delineated relationships between a limited number of variables (McCracken, 1988).

Category Identification

In total, 73 themes were identified from the 19 cases. Putting similar themes together throughout the data collection process developed affinity groups or categories of data. As more themes were identified, they were added to the groups. In some cases, the groups were redefined or took on a different character with the addition of the new data. This is an example of the concurrent data collection, analysis, and theory development that is a hallmark of grounded theory methods (Glaser & Strauss, 1967). The affinity groups continued to morph and change throughout the study until all the data were included. The final affinity grouping of themes resulted in eight categories. These eight categories are:

- Informal relationships between organizations in the enterprise – characteristics include trust, openness, frequency of interaction, team building activity, investment of effort into relationship
- Formal relationships between organizations in the enterprise – characteristics include contract structure, risk sharing arrangement, and length of relationship
- Execution and measurement strategies for the program – characteristics include use of metrics, division of responsibility, authority, and accountability, and disciplined work processes
- Role of the Program Manager – characteristics include interaction with the external environment and management of the boundary of the program
- Organizational structure, both formal and informal – characteristics include social networks individuals utilize to share knowledge, tenure of individuals in various positions, organizational alignment with program lifecycle phase, and skill utilization

- Communication – characteristics include span of information flow, openness, frequency, and transparency of decisions
- Use of standard practices – characteristics include common practices shared across organizations and development, use, and assessment of best practices
- Influence of technology on program execution and performance – characteristics include ownership of technology, investment in development, risk, and reliance on other organizations for key technologies

Figure 4 shows an organization of these categories based on the number of themes per category. This is a pure count of themes per category; duplicate themes cited by multiple programs were counted separately. The figure also indicates the percentage of programs with at least one theme in the category.

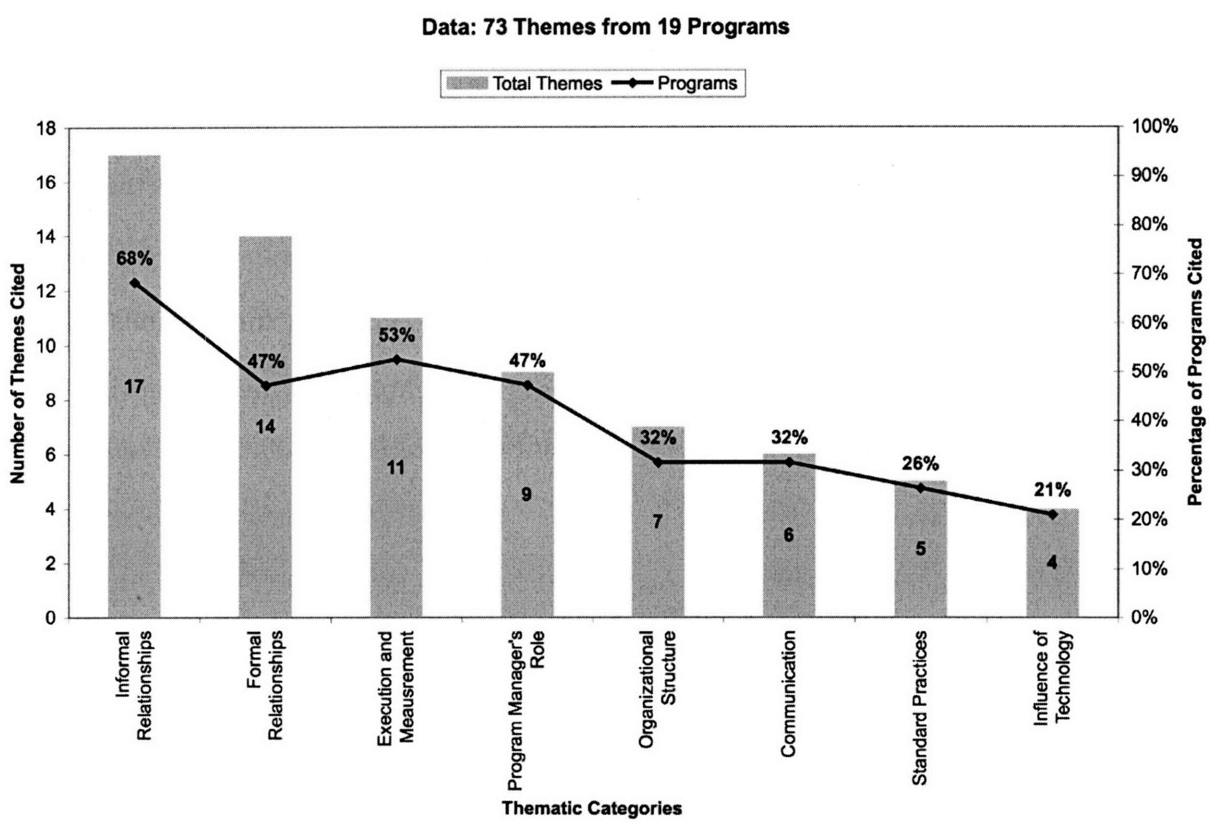

Figure 4. Categories of Patterns Across Cases

This analysis indicates some difference in importance based on emphasis, especially between the most cited category and the least. Clearly there is a difference between a category with 17 themes and one with 4, but where to draw the line between categories is not clear. There is not much distinction between any two sequential categories since the difference is no more than three themes between neighboring categories in the Pareto analysis. Looking at the other information shown in the graph provides a clearer difference between categories. Each of the top four categories was cited by nearly one-half of the programs studied. The remaining four categories were cited by no more than one-third of the cases studied. Without consideration of program performance, this analysis suggests that the top four categories are important to program execution based on the frequency they were cited and the number of programs that cited them.

Subcategory Identification

As mentioned before, several of the categories contained duplicate or closely related themes that were cited by different programs. Looking at the number of duplicate themes per category indicates subcategories that have been emphasized across the cases. Figure 5 shows the same information on the bar graph as in Figure 4, but in this case the bars are sub-divided to show the unique themes in the category, indicating the number of subcategories by the divisions within each bar. For each category, the most repeated theme is on the bottom of the bar, moving to the least repeated theme at the top of the bar.

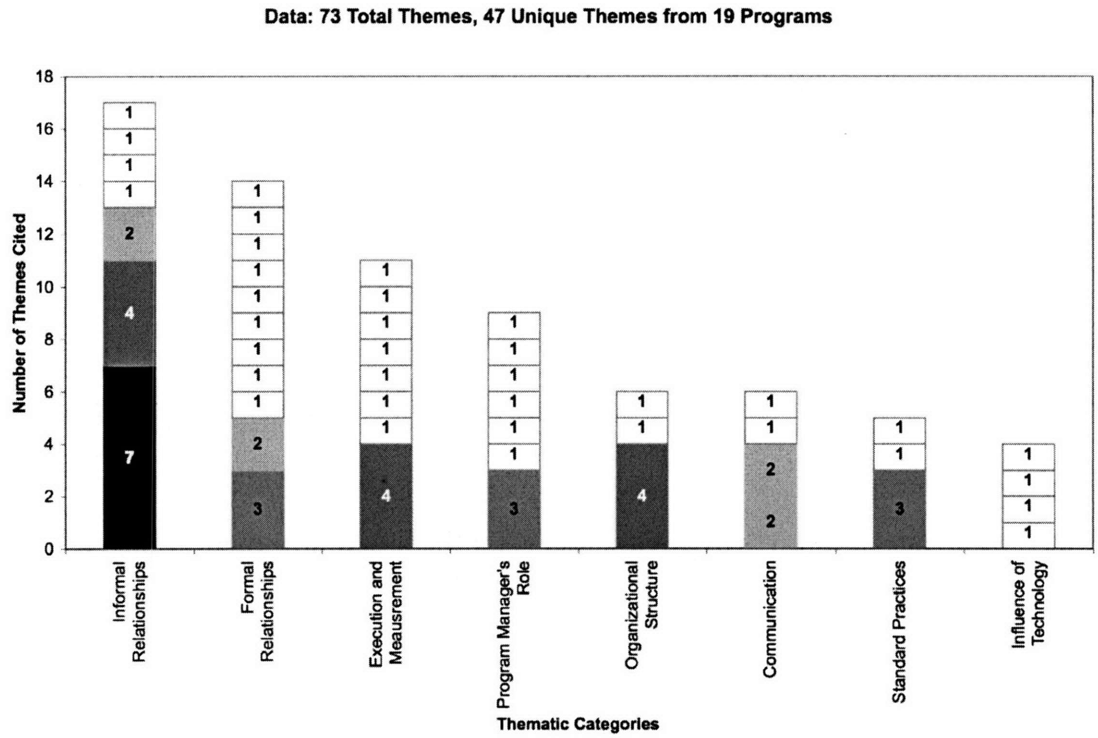

Figure 5. Frequency of Themes

Based on this figure, of the 73 total themes, 47 were unique. Eleven of those 47 were cited by more than one program (blocks shown as 2, 3, 4, or 7 in the figure). In addition to the four categories identified by considering frequency cited, these repeated themes warrant mention based on the emphasis given across the cases; they are listed below in order of frequency. To avoid confusion, there are only ten subcategories listed instead of eleven, as identified in Figure 5. This is because there were two closely related themes both having to do with the use of social networks. In one instance they were identified as useful for navigating the formal organization and in other instances they were cited as creating communication channels. With regard to both communication and navigating the formal organization, interviewees responded that, *"it's about how long you've been around and who you know"* and that, *"these networks are critical."* Although these two subcategories were not linked within the same category, they are quite comparable. Because of their similarity, they have been combined into a single subcategory. This subcategory is listed in order based on its combined total frequency.

- Teaming relationships between organizations built on trust (cited 7 times)
- Use of informal networks to navigate the formal organizational structure (4) and create communication channels (2) (total of 6)
- Interdependence among organizations in the program, for example, reliance on suppliers for success (4)
- Tracking personal accountability for plans and outcomes (4)
- Contract structure mirrored throughout the program from customer to integrator to suppliers (3)
- Management creating a "safe environment" for the program, either through insulation or buffering from the environment (3)
- Use of standard program management "best practices" (3)
- Putting extraordinary effort into customer satisfaction (2)
- Balance of risk among organizations in the program (2)
- Open information sharing with no surprises (2)

Table 8 summarizes the categories and subcategories highlighted through the analysis of the data. Four categories and ten subcategories stood out by the number of themes in each category, the number of cases represented in each category, and repetition of duplicate themes across programs within the categories. Of the ten subcategories identified, seven of them were from the top four categories. Only one category is not represented at all, the *Influence of Technology*. Themes in this category were cited by programs that were able to leverage high maturity of the technologies in the system or by programs that were facing significant technical challenges. In either case, whether technology was helping or hindering the program, the influence of technology did not appear as the foundation of program execution. Themes related to the influence of technology were also cited least overall within the case studies.

Table 8. Summary of Categories and Subcategories

Category (listed by emphasis)	Relationship of Subcategory to Category	Subcategory (listed by emphasis)
Informal relationships between organizations in the enterprise		Teaming relationships between organizations built on trust
Formal relationships between organizations in the enterprise		Use of informal networks to navigate the formal organizational structure and create communication channels
Execution and measurement strategies for the program		Interdependence among organizations in the program, for example, reliance on suppliers for success
Role of the Program Manager		Tracking personal accountability of plans and outcomes
Organizational structure, both formal and informal		Contract structure mirrored throughout the program from customer through integrator through suppliers
Communication		Management creating a "safe environment" for the program, either through insulation or buffering from the environment
Use of standard practices		Use of standard program management "best practices"
Influence of technology on program execution and performance		Putting extraordinary effort into customer satisfaction
		Balance of risk among organizations in the program
		Open information sharing with no surprises

Subcategory Analysis

Although the interviews and documents reviewed did not provide enough data to explore every subcategory, consistent information was available from the responses to particular interview questions which provides some insight about a few of the subcategories. Specifically, the top two subcategories covering relationships between organizations in the enterprise and the use of informal networks can be investigated more deeply through these additional data.

All interviewees were asked about how people on the program interact with each other, specifically across organizational boundaries. This led to descriptions of both individual and organizational relationships varying from close-knit, open, and team-like to rigid, formal, and arms-length. These data are directly related to the subcategory of teaming relationships between organizations built on trust. The second question had to do with whether people had and used a personal network of contacts outside of the program to help them do their job on the program. Responses to this question varied from extensive use of these networks (on a weekly or even daily basis) for a wide variety of tasks to use of these networks only in extraordinary circumstances where help was needed, usually during some sort of crisis. This is clearly related to the subcategories discussed previously of informal networks used to enable communication and to navigate the formal organization.

To examine each of these areas, after the data were collected, a 3-point scale was developed for each area, as shown in Table 9. These are subjective scales, anchored on both ends by empirical support from the cases studied. They represent the spectrum of cases observed. This style of rating is similar to benchmarking studies. Programs on the high and low ends anchored the scales, with the middle category representing the broadest range of variation. I subsequently rated each program, using the scale, based on evidence from the interviews and public documents.

Table 9. Benchmarking Scales for the Two Most Noted Subcategories

Area	1	2	3
Relationships between organizations	Arms length relying on formal mechanisms to dictate interaction	Mixed (either depending on organization, or depending on time)	Teaming partnership including both formal and informal interactions
Use of informal networks	Only in crisis (when extraordinary help is required)	Regularly for only a select group of tasks (e.g. expert review)	Extensively for a wide variety of tasks (weekly or more frequently)

Table 10 and Table 11, shown below, illustrate the benchmarking data across the cases studied. The data are sorted by both the benchmarking scale and by program record. The pie charts show the percentage of programs in each benchmarking bracket based on program record. The left-most column shows the total for all programs.

Table 10. Enterprise Relationship Benchmarking by Program Record

	Total	Best in Class	Successful	Mixed Record	Not on Track
1 - Arms Length	21%	0%	0%	29%	100%
2 - Mixed	32%	0%	80%	29%	0%
3 - Team	47%	100%	20%	43%	0%
Sample Size	19	5	5	7	2

Table 11. Use of Knowledge Network Benchmarking by Program Record

	Total	Best in Class	Successful	Mixed Record	Not on Track
1 - Arms Length	26%	0%	20%	29%	100%
2 - Mixed	26%	20%	20%	43%	0%
3 - Team	47%	80%	60%	29%	0%
Sample Size	19	5	5	7	2

While there are interesting observations about the spread of all programs across the three levels, it is particularly interesting to contrast the tendency for the Best in Class programs to rank higher and the tendency for the Not on Track programs to rank lower. This stands out in both of the examples.

These results are important in at least three ways. Recall that these data were collected primarily from responses to particular questions asked during the interviews. The interview questions were developed based largely on thinking about how to apply the X-teams theory (Ancona et al., 2002) to enterprises. There was an initial premise to this work that the team-level concepts were scalable or had analogous (recognizable) manifestations at the enterprise level. These results confirm this premise. Second, these results also help to verify the X-teams theory by providing evidence that the theory holds in a setting outside of the original research used for theory development. Third, these results suggest that the subcategories identified can be developed into a theory for high performance enterprises that will successfully differentiate program record.

Identifying X-Enterprise Characteristics

Before moving ahead and inductively constructing a framework based solely on the analysis of the case study themes, it is appropriate to return to the original motivation of this work, the X-team characteristics. Although this is something of a sidebar in the sequence of analysis of the case study data, returning to the X-teams theory provides an opportunity for deductive analysis by comparison of the interim results thus far with the characteristics. This is an important external check on the ten subcategories that have emerged, and it provides a way to verify the plausibility of the findings before proceeding.

At the outset of this work, application of the five hallmark characteristics of X-teams to enterprises was considered. There was evidence presented in the first chapter based on in-depth study of the F/A-18E/F that X-enterprise characteristics could be defined, with some similarity and some extension to the team-level characteristics. This section returns to this initial exploration and adds detail to possible X-enterprise characteristics from categories and subcategories identified in the other cases.

Recall that the five X-team characteristics are: external activity, extensive ties, expandable three-tier structure, flexible membership, and internal mechanisms for execution (Ancona et al., 2002). Based on literature and the Super Hornet case, it was postulated that each of these characteristics had either direct or analogous application at the enterprise level. The following table summarizes the similarities and differences between the team and enterprise levels after adding supporting information from the other cases conducted.

Table 12. X-team Characteristics Evidenced by Subcategories Used to Identify X-enterprise Characteristics

<table>
<tr><th>Team Level (Ancona et al., 2002)</th><th>Relevant Subcategories</th><th>Enterprise Level</th></tr>
<tr><td rowspan="2"><u>External Activity:</u>
Ambassadorial, scouting, and task coordination boundary spanning activities between all individuals in the team and its environment</td><td>• Management creating a "safe environment for the program, either through insulation or buffering from the environment
• Putting extraordinary effort into customer satisfaction</td><td><u>External Activity:</u>
Ambassadorial, scouting, and task coordination boundary spanning activities between a the enterprise leadership (as representatives of the enterprise) and the environment – emphasis on the ambassadorial activity</td></tr>
<tr><td>• Teaming relationships between organizations built on trust
• Interdependence among organizations in the program, for example, reliance on suppliers for success</td><td><u>Internal Boundary Activity:</u>
Ambassadorial, scouting, and task coordination boundary spanning activities across organizational boundaries within the enterprise by many individuals in the enterprise – emphasis on the scouting and task coordination activities</td></tr>
<tr><td><u>Extensive Ties:</u>
Development and utilization of individual social networks for the benefit of the team</td><td>• Use of informal networks to navigate the formal organizational structure and create communication channels</td><td><u>Extensive Ties:</u>
Identical to X-teams, although especially critical for enterprise leadership</td></tr>
<tr><td><u>Expandable Three-tier Structure:</u>
Core, operational, and outer-net tiers not aligned with organizational hierarchy</td><td>• Teaming relationships between organizations built on trust and institutionalized in the core tier</td><td><u>Expandable Three-tier Structure:</u>
Core, operational, and outer-net tiers not aligned with organizational hierarchy or organizational boundaries; at the enterprise level, each tier must be represented in the major organizational players involved</td></tr>
<tr><td rowspan="2"><u>Flexible Membership:</u>
Ability of individuals to transfer between tiers, as well as onto and off of the team</td><td></td><td><u>Flexible Individual Membership:</u>
Identical to X-teams at the individual level</td></tr>
<tr><td></td><td><u>Flexible Organizational Membership:</u>
Flexible organizational membership is not practical for enterprises because the coordination and relationship costs associated with substituting one organization for another are much higher than they are for individuals</td></tr>
<tr><td><u>Internal Mechanisms for Execution:</u>
Integrative meetings, transparent decision making, and use of scheduling tools</td><td>• Tracking personal accountability of plans and outcomes
• Use of standard program management "best practices"</td><td><u>Internal Mechanisms for Execution:</u>
Integrative meetings, transparent decision making, and use of scheduling tools among other standardized program management "best practices"</td></tr>
<tr><td></td><td>• Contract structure mirrored throughout the program from customer through integrator through suppliers
• Balance of risk among the organizations in the program</td><td><u>Alignment and Integration:</u>
Shared vision among organizations, balanced risk between organizations, aligned incentive systems, and rigorous application of systems engineering for integration</td></tr>
</table>

In addition to the linkage between the enterprise-level characteristics and the identified subcategories shown in the table, there are a couple of observations worth mentioning. In scaling the team concepts to the enterprise level, the units of analysis change. If enterprise is analogous to team, then an organization is the analog of an individual, i.e. a team is a group of individuals and an enterprise is a group of organizations. This distinction is particularly important for the *flexible membership* characteristic. Scaling the units of analysis consistently, at the team level, flexible membership of individuals is most similar to flexible membership of organizations at the enterprise level. In an enterprise the change costs associated with one organization coming into or leaving the enterprise are significant, and as a result, this is generally never seen. The change costs are so significant that in some cases, such as the Joint Tactical Radio Systems (JTRS) programs studied, the U.S. military customers maintain two major subcontractors throughout the development phase and then have them compete for the production contract. Maintaining redundant capability through the entire design phase is expensive, but it is a way to reduce risks associated with the system, for instance having to rely on a sole source. It would be more costly to recreate the knowledge learned during the design phase so that an alternate contractor could produce the system than it is to maintain redundant capability in the first place. These organizational change costs are much higher than the change costs associated with individuals at the team level.

Perhaps the larger issue with respect to the flexible membership characteristic is in its relationship to the *expandable three-tier structure*. At the team level, flexible membership was not only onto and off of the teams, but also between the tiers of the expandable structure. At the enterprise level, this only makes sense with regard to flexible membership of individuals. Because the tiers of the expandable structure are not aligned with organizational boundaries or hierarchy, there is still flexible membership of individuals between tiers at the enterprise level. For example, in one of the cases studied, a senior manager was brought is as part of an expert review team for a short period on the program. In this role he was part of the outer-net tier. Once the review was complete, there was a list of follow-on actions that needed to be completed. He stayed with the program to ensure those actions were completed and eventually became the program manager, transitioning from the outer-net tier, first to the operational tier, then subsequently to the core tier as he stayed on the program.

Another observation relates to boundary spanning activities at the enterprise level. This has been discussed before, but is worth reiterating here. At the enterprise level, there are internal boundaries (or interfaces) as well as external boundaries. The internal boundaries are between organizations in the enterprise and the external boundary is with the environment. This necessitates boundary spanning activity both internally and externally. Different types of boundary spanning activity are associated with each: external activity relies on more ambassadorial activities whereas scouting and coordination activities largely occur across internal boundaries. This does not preclude the other types of activity from occurring either internally or externally, just to say that there are primary types of boundary spanning that take place in each case. One example of ambassadorial activity that occurs externally is lobbying Congress. Contractors often make concerted information campaigns to inform Congressmen about programs during the budgeting process. They generally do not do this as a particular contractor company, but instead as a coordinated group of companies lobbying for a particular program. One program studied, nearing the end of its production, did this to gain support for more orders for the system program.

The deductive comparison between the subcategories and the X-team practices helped identify and refine a set of X-enterprise characteristics. The enterprise characteristics were suggested by the F/A-18E/F study, but now they are reinforced with additional evidence from 19 cases. Additionally, what was found empirically agrees with existing literature on how the team-level concepts may scale to the enterprise level of analysis.

Summary

Like any other qualitative work, the goal of this work is not for "absolute truth" but to evaluate the plausibility of this interpretation of the data in comparison to alternative explanations (Mishler, 1986). Several layers of analysis were conducted in order to reach the conclusion that the categories and subcategories identified are indeed a tenable starting place for a theory of high performance enterprises. The 19 cases provided comparative data, and the process of analysis was something like peeling an onion. The coding and emergent categories in the outer layer were informative, but not decidedly crisp. Defining subcategories in the middle layer provided additional insight and greater specificity. But in the third layer, analyzing particular subcategories across the cases, the flavor of the data was readily apparent.

Iterating between data collection, analysis, and theory development, this work extends the X-teams theory to a higher level of analysis. Nineteen cases were selected representing many different dimensions of aerospace programs. Data from the case studies were aggregated into themes and then scrutinized in several layers of evaluation. Data analysis resulted in eight emergent categories, four of which represent almost half of the cases (9 of 19). Within the eight categories, ten subcategories were identified as cited by multiple programs. Seven of these ten subcategories fell within the top four categories, providing additional support for the direction of the emerging subcategories. Benchmarking style analysis of each case related to the top two of the ten subcategories indicated an interesting trend of more successful programs having higher ranking and less successful programs having a lower ranking. Although additional work will be required to turn these categories and subcategories into any sort of useful framework, this analysis suggests the empirically grounded patterns that have surfaced from these case studies can be developed into a supportable theory for high performance enterprises.

Chapter 5

Towards a Framework for High Performance Enterprises

Introduction

The categories identified in the previous chapter were useful for a first sorting of the data, but are too general to be particularly helpful in developing a specific theory of high performance enterprises. The subcategories identified are more detailed and provide the starting place for constructing a framework of best practices that distinguishes high performing programs. The framework presented here has emerged from combining the data from all of the cases, the original F/A-18E/F study as well as the additional 19 studies. In that regard, it is a hybrid of practices from many different cases. In total, the cases represent over 130 interviews, document review, and observation of program meetings (during the in-depth F/A-18E/F study) from 11 different organizations. The combined data set spans customer, system integrator, and major subcontractor organizations as well as several different layers of the organizational hierarchies. The framework developed in this chapter summarizes the case data into a coherent picture of the distinguishing factors for enterprise performance.

Framework

As shown in Figure 6 below, enterprise behavior is divided into individual and systemic behaviors. Desired systemic behaviors are, of course, enacted by individuals, but they are shaped by structures, both formal and informal. The framework has three main sections: distributed leadership actions representing desired individual behaviors, informal structures and formal structures, the latter two together representing desired systemic behaviors. The word structure is used here colloquially, referring generically to an arrangement of parts of the enterprise.

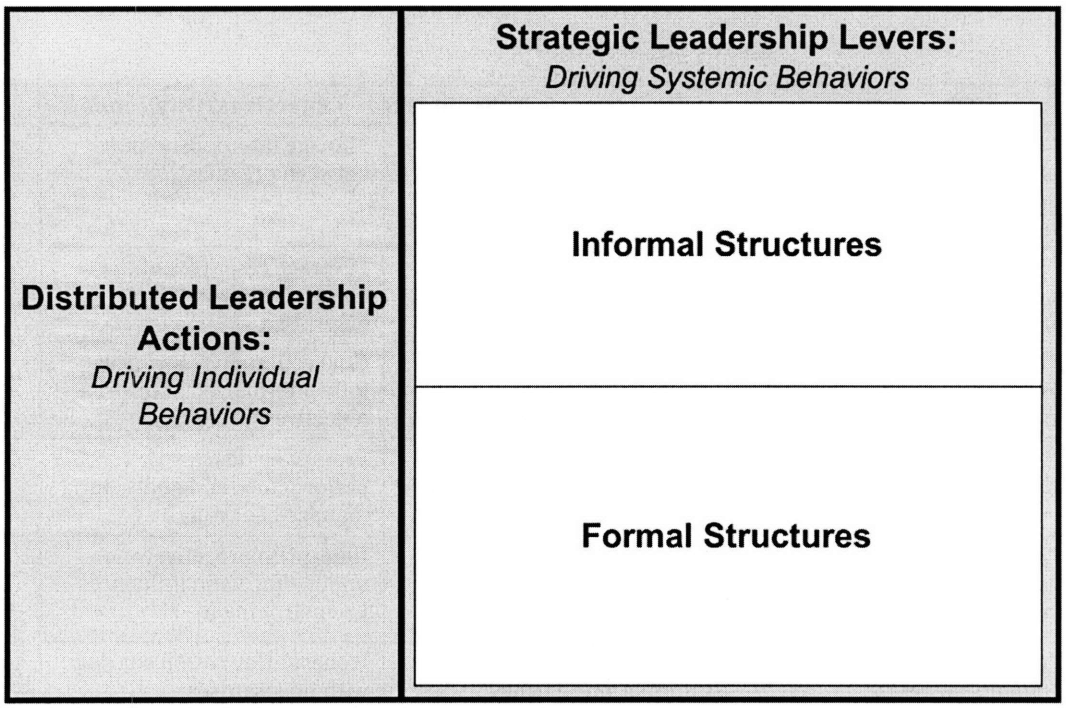

Figure 6. Meta-organization of the Enterprise Framework

Each section includes the key behaviors or structural elements that were identified from the subcategories of the case study data identified in the previous chapter. In order to make these subcategories useful, the specific insights and observations had to be abstracted to a more general level describing the structure or behavior and the desired outcome or objective. These generalizations became the elements of the framework. The elements have strong ties to the subcategories from the case study data, but they obviously do not represent everything that could be associated with any particular section of the framework. Part of the value of empirical results is a sorting between what is important and what is not. In this way, the framework does not attempt to be exhaustive in each section. This framework simplifies the complexity of all potential influences on the enterprise to the essential drivers for each section. Table 13 below relates observations from the cases studied for each data subcategory to the structural or behavioral elements of the framework and the objectives/outcomes of the enterprise. It also summarizes the following discussion.

Table 13. Framework for High Performance Extended Enterprises

		Observation	Structure or Behavior	Objectives/Outcomes		
Individual Behaviors	Distributed Leadership Actions	*"Relationships with our suppliers, partners and sister divisions are critical to our success"*	Boundary spanning activity across organizations in the enterprise	Manage interdependence between organizations	Develop and Advance the Culture	Empowered Workforce and Robustness
		"It's about who you know, your network is critical to your success"	Developing and utilizing a social network	Leverage resources of the enterprise beyond the enterprise		
		"Focus on the customer relationship so they can help fight for the program"	Developing and sustaining extensive customer interaction	Goal congruency through fully internalized enterprise objectives		
		"People own their plans and deliver on them - no excuses"	Fostering and maintaining personal accountability of plans and outcomes	Prompt feedback on performance and ability to manage behavior		
System Behaviors	Informal Structures	*"Management creates a safe environment for the program"*	Boundary spanning activity with the enterprise environment	Enterprise proactively understands and influences its environment	Dealing with Unknowns	Effectiveness and Flexibility
		"Open information sharing with no surprises"	Encouragement for open information sharing	Honest information sharing with no surprises		
		"Emphasis on relationships creating strong partnerships built on trust"	Veteran core group to institutionalize behavior	Sustained high levels of interorganizational trust		
	Formal Structures	*"Balanced risk between all players"*	Balanced risk through work share and teaming arrangements	Sustainable enterprise value proposition	Manage Knowns	Efficiency and Agility
		"Contract arrangements mirrored through the program from customer through suppliers"	Common contract structure	Single, aligned incentive system		
		"Development and deployment of standard best practice models"	Standardized program management practices (metrics and reporting systems)	Less friction in interactions and interorganizational learning		

Distributed Leadership Actions

As the name suggests, drivers of individual behaviors are distributed through all levels of each organization in the enterprise. Distributed leadership is the ability to spread leadership responsibilities, activities, and engagement throughout all levels and across all organizations of an enterprise. Senior leadership acts as a role model and helps mentor individuals in distributed leadership actions. These individual behaviors develop and advance the culture of the enterprise. Individual actions continually test and over time reinforce the enterprise culture. Enterprise culture is the set of shared assumptions, values, and norms that govern interactions among individuals in the enterprise and with the external world (Schein, 1985). Enterprise culture reflects the level of trust between organizations in an enterprise, the ability to share knowledge between different players, levels of commitment to the enterprise vision, and mutual accountability, among other things. A specific example of how an enterprise culture is developed is creating a personal connection between their individual actions and the enterprise vision. In one of the cases studied, the program goals were established in a strategic roadmap with high-level goals and metrics. Everyone on the program was responsible for setting individual goals that related to the program goals. Progress towards these individual goals was part of the employees' annual performance reviews, and the individual goals were aggregated at each level of the organizational hierarchy in such a way that progress towards the overall program goals could be measured. The strategic roadmap for the program covered several years, but lower-level individual goals were updated on a more frequent basis. Through this connection between the individual goals and the program goals, which was specified by the senior leadership, the enterprise vision became a collective, shared vision with buy-in and a sense of ownership at all levels of the enterprise. In fact, it is only through a distribution of leadership that the enterprise vision can be fully internalized, creating a clear line of impact between individual goals and enterprise vision. Distributed leadership actions are also an important way to leverage resources in the enterprise. Distributed leadership provides ways to combine individual skills and knowledge to support the needs of the enterprise. This is reflected in what is described as a "team-based culture," where it is common to form ad hoc teams to address enterprise issues. Four distributed leadership actions that drive enterprise performance are shown in Figure 7 and will be discussed below: boundary spanning activity across organizations in the enterprise, developing and utilizing a social network, developing and sustaining extensive customer interaction, and fostering and maintaining personal accountability of plans and outcomes.

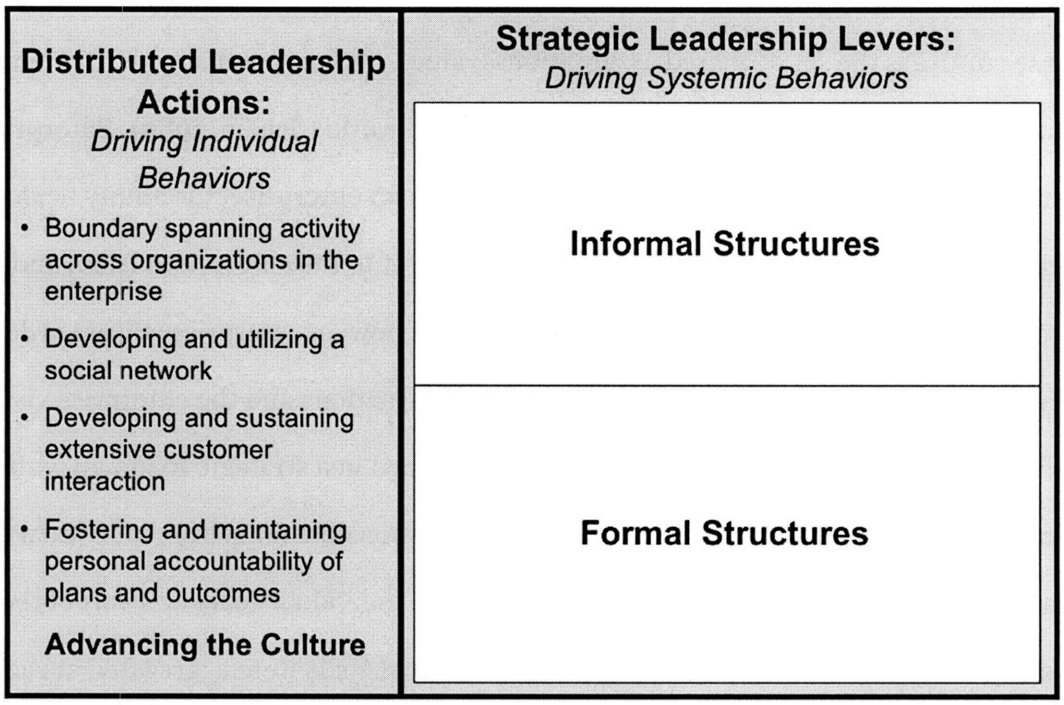

Figure 7. Elements of Distributed Leadership

<u>Boundary Spanning Activity Across Organizations in the Enterprise</u> represents all interactions between individuals in the enterprise across organizational boundaries. This activity generally falls into three categories: managing upward, lobbying for resources, and maintaining credibility (ambassadorial), identifying knowledge and expertise (scouting), and managing laterally (task coordination) (Ancona & Caldwell, 1992).

Traditionally, these boundary spanning activities occur at the domain where an organization interacts with its environment (Scott, 1992). In an enterprise, or network of organizations, boundary spanning activity occurs not only where the enterprise interacts with its environment, but also where organizations within the enterprise interact with each other across organizational boundaries. In a boundary-permeable structure such as an enterprise, the bureaucracy-based buffers of a traditional hierarchy are removed, and the need for boundary spanning activity increases. Additionally, responsibilities for these activities must migrate to lower levels of the organization, being more broadly diffused (Cross *et al.*, 2000). Within an enterprise, boundary spanning activity across organizational interfaces occurs frequently at many levels. An important way to manage the interdependence between organizations is by having counterparts in both organizations working closely together.

Of particular emphasis in the cases studied was the reliance on partners, suppliers, and sister divisions for knowledge, resources, coordination, and deliverables (e.g. parts, subsystems, software, design information, process capabilities etc.). This reliance is the result of increasing system complexity, such that no single organization has the required expertise or willingness to assume the risk and financial obligations of modern programs. Reliance on other organizations necessitates boundary spanning activity. Aerospace programs are truly integration efforts not only on the technology side, but also on the organizational side. Effective integration relies on contact and interaction at all levels of the enterprise. A program may have five or six levels of nested teams, responsible for corresponding scopes of work. It is typical to have technical, programmatic, and contractual interfaces at each level. For example, on a military aircraft program, there may be a weapons system team responsible for the aircraft system, the training system, the engines, the avionics, and so on. Under this team would be an aircraft team responsible for the flying system, under that there would be a forward fuselage team, an aft fuselage team, and a wing team, among others, and under the wing team there would be a skins team (external surfaces), a spars team (internal structure running from the body to the wing tip), a ribs team (internal structure running front to back in the wing), a side of body team (where the wing mates to the aircraft), a control surfaces team (for flight control structures such as ailerons and flaps), and so forth. Any of these teams would coordinate with suppliers, manufacturing, tooling, testing, and so on for support for their work. When these interfaces become organizational bottlenecks, integration becomes impaired. Of course, coordinating boundary spanning activity into each organization's internal processes is critical. The boundary spanning activity cannot be done in isolation of the internal processes and knowledge sharing. If this is done properly, a virtuous cycle develops over time where the boundary spanning activity reinforces an organization's internal processes, and subsequently their performance (Ancona & Caldwell, 1992).

Developing and Utilizing a Social Network is related to the ties between individuals made by creating and maintaining relationships. Although social networks are pervasive in every day life (e.g. friendship networks, hobby/activity networks), social networks develop in professional settings by working with someone over time. Nearly everyone has a social network of colleagues they engage with on a regular basis. This network can be broadened through rotation programs or switching jobs. Based on their connection to the enterprise, individuals will have part of their social network in common, but part will be unique based on their individual experiences. The common parts of the enterprise network link the uncommon parts of the individual networks. Collectively, this creates an extensive knowledge network for the enterprise as a whole.

Another way to link professional social networks is through mentoring programs where the mentor relationship links two previously separate social networks. Each time networks are linked, they grow, providing access to new and different resources and sources of information. Social networks provide communication channels and they provide assistance in navigating the formal organizational structure. The larger the network, the more potential exists for the enterprise to tap into. The social network of each individual that resides outside the enterprise is of particular interest. By utilizing the unique parts of their social networks, individuals bring more resources than their own knowledge and skills to the enterprise.

Utilizing a social network is particularly appropriate as a distributed leadership action since it is an inherently individual behavior. Consider how a social network link can be used as a communication channel. Programs can sometimes become islands with their companies, with little coordination between them, even though they often share technologies and resources. But in one case, the Program Manager (for Program A) cited close coordination with another program (B) because the Program Manager for B used to be the Operations Manager for A during his last job assignment. The experience of working together created a foundation for communication even after they were no longer working on the same program. The relationship between the two Program Managers made communication and coordination between the two programs more likely than if they did not have any connection. The existence of common knowledge is a prerequisite for effective communication between different specialists (Demsetz, 1991). At an individual level this common knowledge will be greater than at a more collective level, where in general increasing the scope of information being shared and integrated decreases the efficiency of communication and information sharing (Grant, 1996).

In the cases studied, people frequently cited the importance of knowing who to talk to and how to find them. Social networks are built of relationships with either strong or weak ties (Burt, 1992; Granovetter, 1973, 1983). Ties are another word for the link between two individuals in a social network. Weak ties are good for identifying unique knowledge (Granovetter, 1973, 1983; Hansen, 1999), and strong ties facilitate cooperation and transfer of complex knowledge (Krackhardt, 1992). The strength of tie is based on the frequency of contact, the amount of common knowledge, the trust between individuals, and other characteristics that loosely relate to the "closeness" of the individual relationship. An example of the difference between weak and strong ties is the difference between acquaintances and good friends.

In every case studied, individuals provided examples of calling on their social network during crisis situations, when extraordinary help was needed. In many cases, a social network was also utilized to engage outside expertise, for example, to identify subject matter experts that are not resident on the program to conduct a review. In the industry, these are called "red team reviews," and are often done with a group of experts from outside of the program before a major program milestone. In a few cases, individuals used their social networks on a regular basis, calling on them frequently for expertise, a different perspective, resources, or sometimes just fresh set of eyes. One Chief Engineer described attending weekly meetings in the production area, not because he needed to be there, but because it helped develop his network. *"It's mostly half an hour spent watching the grass grow, but I get to learn their problems, I get to know faces, and they get to know mine. It's a good half hour of my time in terms of being seen and seeing people. It helps reduce the them and us mentality."* A Program Manager indicated picking up the phone and calling on his network frequently, but noted, *"it works two ways, I do what I can to help out when people call me too."* People who engaged their contacts more frequently had better access to their networks. They had more practice using their networks to identify and seek out useful outsiders (Hansen, 2002).

Developing and Sustaining Extensive Customer Interaction is the third distributed leadership action. Customer satisfaction has been seen to be a particularly strong driver of individual behavior in organizations adopting Lean, Six Sigma, or other continuous improvement approaches centered on customer value or the voice of the customer (Murman *et al.*, 2002; Womack & Jones, 1996). More than giving lip service to customer satisfaction, enterprises that are committed to sustaining close and frequent interaction with their customers must rely on distributed leadership to fully internalize this vision. There is significant power to align an enterprise when individuals' actions and decisions are based on active engagement with the customer. Greater customer interaction gets them personally involved in the enterprise, and when everyone is working towards a common goal of pleasing the customer, tradeoffs are more straightforward. The priority becomes whatever is in the best interest of the customer.

In the enterprises studied, examples were given of programs putting exceptional effort into working with the customer to ensure they are satisfied. The examples ranged from including customers in individuals' annual reviews where appropriate (using a 360° review approach to incorporate those above, below, and peer with the individual), to having customer representatives onsite at various organizations, to having customers involved in decision making even where they did not have authority over the decisions in order to keep them informed, to using informal channels to communicate with the customer in order to share information quickly and effectively because *"it's the right thing to do."* The more extensive the interactions with the customer were, the more the customer became an integral part of the enterprise. This allowed the customer perspective to be more clearly understood, and allowed the customer to participate more fully in the program. One Program Manager remarked, *"when something goes wrong, I call my counterpart at the customer first, then I call my boss."*

Once the customer is an integral part of the enterprise, the view of who the customer is can shift. In some of the most successful enterprises studied, the system integrator, their partners, and the customer (system acquirer) all worked together towards satisfying the end user customer. In many regards this is a redefinition of the enterprise boundaries, moving the acquirer customer into the enterprise with the goal of providing value for the ultimate customer. This is a powerful concept that in practice overcomes some of the conflicting objectives between organizations by providing a single, unifying, top priority to base decisions on.

Fostering and Maintaining Personal Accountability of Plans and Outcomes is the final distributed leadership action. Often responsibility for work and even authority (over resources) to do the work are distributed, but accountability is not always distributed to the same level.

When accountability is distributed to the lowest level of control, and individuals are held to that, variation in performance will be readily apparent. When accountability is aggregated, confounding factors can mask both good and bad performance. Excuses can be made for poor performance and good performance can go unnoticed.

Holding people accountable for their plans promotes accurate planning instead of inflated estimates. Holding people accountable for their outcomes ensures they not only create realistic plans, but that they formulate approaches which are feasible and ask for help when it is needed. Of course unexpected events will always occur. Personal accountability is not to suggest that unplanned anomalies or even mistakes will not be tolerated, simply that poor planning and execution will not be excused.

Accountability was emphasized over and over again in the programs studied. In some cases, this was so engrained in the program that the ability to meet commitments was cited as a measure of success for the program. In one program, in order to ensure personal accountability, all schedule and budget margins (management reserve of resources held aside to account for uncertainty in the plans) were held at the system level instead of distributed; in order to get additional resources, the request had to be clearly justified and traded-off with the needs of other elements in the system. The ability to make good plans and manage to them was often cited as an important driver of enterprise performance.

Strategic Leadership Levers

The distinguishing features of the elements in this section are that they have longer-term implications and are salient to the senior leaders in the enterprise. These strategic leaders control or influence formal and informal structures meant to drive systemic behaviors. The structures not only drive systemic behaviors, but they can sustain them when the behaviors become institutionalized. As these systemic behaviors become institutionalized, they shape the enterprise culture. This works hand in hand with the individual actions in the distributed leadership section that reinforce and advance the program culture that have been shaped by the informal and formal structures. Shaping and reinforcing enterprise culture are one example of how the distributed leadership actions and strategic leadership levers work together synergistically.

Informal Structures

The informal structures are developed to anticipate and maximize opportunities, which allows the enterprise to deal with "unknowns" that occur. Unknowns are things that cannot be planned for *a priori*. In every enterprise, because of uncertainty, ambiguity, and limited foresight, not every aspect of an enterprise can be explicitly defined from the outset. In addition to dealing with unknowns, informal structures deal with intangibles such as communication effectiveness and trust. Three informal structures that are influential drivers of systemic behaviors are: boundary spanning activity with the enterprise environment, encouragement for open information sharing, and a veteran core group to institutionalize behavior. They are shown in Figure 8 below and will be discussed subsequently in detail.

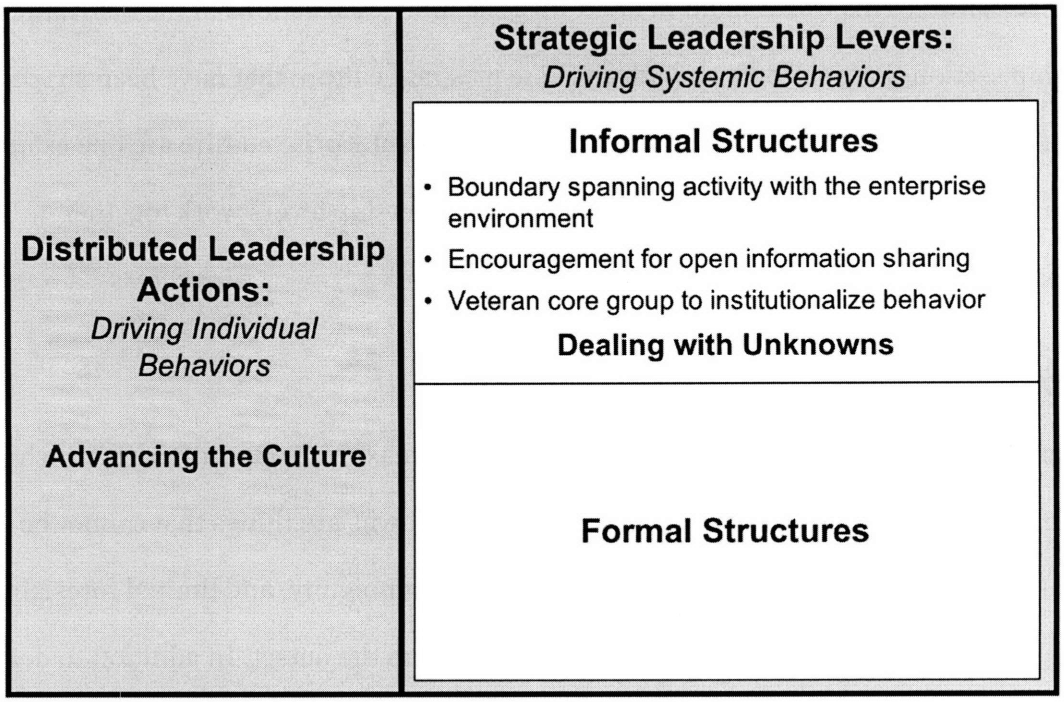

Figure 8. Elements of Informal Structures

Boundary Spanning Activity with the Enterprise Environment is an important role of externally oriented program management. Those in program management roles often have a unique purview of both the internal workings of a program and its external stakeholders. External stakeholders in the enterprise environment include regulators, Congress, local communities, media, shareholders, corporate management, competitors, and labor unions, among others. These stakeholders can affect and are affected by the enterprise, but are on the periphery of the program (they are not central to the execution of the program). Program managers tend to be either internally or externally focused, depending on personal style. Particular orientations may be better suited for various phases in the program life. During the concept exploration phase when requirements are being defined, it maybe most useful to have an externally oriented program manager who can readily identify and communicate changes. The early phases of the program typically involve churning between all organizations involved to get the system specifications and working arrangements identified as various options are explored; new information also comes in from a wide range of sources. On the other hand, towards the end of detailed design into the transition to production, a more internally focused program manager may serve the program well by focusing on execution and integration challenges. In two of the cases studied from two different companies, the Program Manager who led the conceptual design, proposal, and essentially "got the win" was admittedly externally oriented. Shortly after the program moved into detailed design, these managers were moved into roles developing strategic partnerships to take advantage of their style and new program managers were brought in to lead the detailed design work. In both cases, the new program manager had a more internal focus on planning and executing to plan. This was helpful during this phase of the program, which requires close attention to internal coordination. In general, program managers tend to be internally focused, but an external orientation provides several advantages. This internal focus may be reflective of how program managers are trained, but those with significant experience have often gained an appreciation for an external perspective.

Boundary roles, such as that of program managers, have primary functions of providing external representation and processing information across boundaries. At the enterprise level, both of these functions serve to link enterprise structure to environmental elements, through buffering, moderating, or influencing the environment (Aldrich & Herker, 1977). One way of influencing the environment at the enterprise level is managing many different stakeholders simultaneously. Effectiveness of an interorganizational network relates to the ability to manage powerful stakeholders across boundaries (Sydow & Windeler, 1998). These powerful stakeholders influence managers based on how strongly the managers believe the stakeholders contribute to their success (Pfeffer, 1972). Those with an external orientation actively engage the external stakeholders. This improves communication flow and subsequently understanding of different perspectives. The external stakeholders gain a better sense of what is impacting the enterprise, and the program management gains a better sense of changes in the environment that may affect the program. In addition to managing powerful stakeholders, program managers often face challenges in having to manage upward to establish credibility and lobby for resources, identifying sources of knowledge through scouting, and coordinating tasks across boundaries. While boundary spanning is important at all levels within the enterprise to manage the interdependence between organizations, it is essential as a strategic leadership behavior to manage the boundary between the enterprise and its environment.

An example of externally oriented program management from the cases studied was the ability of the program management to create an atmosphere of security and safety within the program by buffering it from external attacks. In the cases of new technology development, this meant keeping corporate leadership aware of emerging technology development while giving the program time to develop and realize its potential. In the cases of mature technology integration efforts, this meant exposing the program to more of the environment to encourage finding innovative approaches and experimentation to improve on the conventional approaches. In every case, an external orientation allows the program management to be proactive rather than reactive to its environment. Part of this is a paradigm shift away from thinking of the environment as a hard constraint, which requires responsive behavior, to thinking of the environment as something that can be influenced proactively. The more information the enterprise has about the environment the more surprises can be prevented, promoting open information sharing that is critical as discussed in the next section.

Encouragement for Open Information Sharing is a critical component of the informal structures of a high performance program. In order to actually achieve truly open sharing, it has to be expected, enabled, and reinforced consistently. Senior leadership must exhibit open information sharing themselves, acting as role models and setting the tone for which behaviors are tolerated in the enterprise. Leading by example, they quickly promote or limit information sharing. If someone brings information forward that is unexpected or not good news and they are offered help to solve the problem, they will be more likely to continue to bring information forward. In this scenario, the problem can be addressed and resolved without escalating out of proportion, or lingering until it becomes a much bigger challenge. If, on the other hand, they bring information forward and are berated or punished in some way, they are less likely to bring information forward in the future.

In transferring knowledge, both transparency and the receptivity of the exchanging parties are important. Transparency allows for the knowledge to be disclosed and receptivity allows for knowledge to be absorbed or used collectively to generate knew knowledge (Larsson *et al.*, 1998). Maintenance of this open information sharing requires continual effort both in the sharing and receiving roles. Putting in place mechanisms that encourage or actually require people to bring information forward is important. For example, requiring discussions about help that is needed during meetings is one practice that encourages people to bring forward information. Round robin discussions where everyone takes a turn to contribute their input is another way to encourage sharing. Open information sharing is enabled through common communication infrastructure, identical but distributed points of access to real time information, and a feeling of security to speak freely.

Informal systems used by senior leadership that reward people for bringing forward information and punish them for not bringing forward information in a timely manner can be a starting place to develop trust between individuals and their management. Once individual trust is established, it is continually tested every time a new opportunity to share information arises. Because open sharing relies on trust, it is fragile. It only takes one breach of that trust to limit the exchange of information. Consistency in these informal systems, where behaviors align with expectations, strengthens and builds the trust between the individuals. This in turn strengthens the open sharing atmosphere and the willingness to share freely in the future.

Open information sharing was identified as important to nearly every case studied. Very few cases had actually achieved it. This is one element that is much more challenging to be successful at than it is to describe. A particular example of this is how people interact in meetings where there are representatives from other organizations. In programs where there is truly open information sharing, it does not matter which badge people are wearing, it does not matter who is attending the meeting, or what gets said. There is no filtering, and information and reactions are shared in real time. One program studied established a common information infrastructure early in the program and diligently uses their intranet to share information between organizations. They have a section designated for program meetings where all presentations are posted before they are made and then archived. During the meeting, all presentations are made directly from the meeting site to ensure everyone, even if they're not in the same room, can look at the same presentation. These program meetings typically included customer, system integration, and major subcontractor personnel, all viewing the same information in real time. In contrast, in many enterprises, open information sharing is talked about but not achieved. One major subcontractor described not being able to communicate with the customer without the system integrator's approval and presence during any discussion. In this type of situation, meeting agendas are constructed with a special section (usually at the beginning or the end of the meeting) where only specific people can attend the discussion, requiring others to show up after or leave early before specific topics get shared. Additionally, the information is not shared real time; it is reviewed before it even gets on the agenda for the meeting in the first place.

It is difficult to achieve open information sharing, but the benefits are impressive. When there are no surprises in the enterprise, the focus of the organization is shared, and no one is distracted by worrying about who can know which information. In one case studied, the program manager described a time when things on the program were not going as planned.

Instead of hiding this information, they made it known and shared the issues publicly. This brought some unwanted negative attention, but it also allowed the program to share how they were solving the issues before anyone could conclude that the issues were not being properly addressed. It also gave the program the visibility it needed to get the resources required to address the issues effectively. In another example, the program manager described talking to their counterparts at the customer and partner organizations on a daily basis. During these conversations, they shared what was going on in their organizations, and as they got to know each other better, they realized they did not always agree on everything, but even so, knowing each other's position helped them negotiate around conflicts. In nearly every example, open information sharing brings people to the edge of their comfort zone, requiring them to disclose information that could reflect poorly on either them personally or the program. When programs consistently share openly, they gain credibility for being able to manage and solve problems that arise, and they gain an ability to advocate for their work and negotiate through difficulties.

Veteran Core Group to Institutionalize Behavior is the informal structure that is critical to sustain enterprise performance. This core group consists of individuals with significant experience on the program, from a range of positions within various organizations in the enterprise. These long-standing members of the enterprise have established working relationships with each other, they sustain communication channels, and they can leverage knowledge of program history in solving current and future problems. This group plays an important role as the enterprise memory and in indoctrinating newer members in the enterprise culture.

This veteran group is especially important in developing interorganizational trust. Interorganizational trust is developed when trust between individuals in boundary spanning roles is institutionalized so that it remains despite turnover of the individuals involved. When trust becomes a characteristic of the interaction instead of a characteristic of particular individuals' relationship, it moves into the realm of interorganizational trust. Interorganizational trust is a vital aspect of developing sustainable interorganizational relationships that are more than arms-length agreements. Close interorganizational relationships are the result of intensive (and often repeated) interaction, provide rich information channels, and demand loyalty and trust (Gulati, 1995; Ring & Van de Ven, 1994; Sydow & Windeler, 1998; Zaheer et al., 1998). They "are the enduring transactions, flows, and linkages that occur among or between an organization and one or more organizations in its environment" (Oliver, 1990, p. 241). These relationships are more than contractual agreements; they often grow out of personal rapport and shared vision between leaders, but as they become institutionalized and depersonalized over time they provide opportunity for collaboration (Kanter, 1994).

Collaboration is simply entities working together to accomplish more than what any individual entity could do alone. The potential to collaborate can provide real value to the entities involved (Kanter, 1994), but collaboration is often an expected and required behavior of an enterprise. When collaboration is required to meet program goals, the relationship building provides foundations that enable it to be taken for granted. This is often the case in aerospace programs. Relationships built on trust also provide a way to overcome the difficulties of trading knowledge-based assets; this is an important foundation of two parties' ability to collaborate (Sobrero & Roberts, 2001). In fact, development of this relational capability lowers the exchange costs associated with knowledge transfer (Lorenzoni & Lipparini, 1999).

From the cases studied, there are a few examples of high levels of interorganizational trust and several examples of what happens to interorganizational relationships without long-term trust. In one case, the system integrator worked with suppliers to provide "just-in-time" inventory for their production line. One of the challenges of a just-in-time system is calculating the buffer needed to support irregularities in the production line. This is especially true of a mixed-model production line. In this enterprise, suppliers have clear visibility into how much of their product is in the integrator's factory, and when it needs to be replenished, through a web cam system that shows the suppliers' product on the assembly floor. This sort of visibility is the equivalent of having the suppliers resident in the facility; it provides both organizations with flexibility to accommodate changes in the production rate very quickly.

In another case, the program manager indicated, *"we have good relationships until something goes wrong, then everything has to be in writing."* This suggests what happens when there is not a high level of trust between organizations. When trust exists between organizations, they are willing to act without assurance of benefit or penalty; when trust does not exist, organizations act only in accordance with pre-specified and negotiated limits. In this case, the capability of the enterprise is limited to the behaviors that could be accounted for when the relationship was negotiated; emergent opportunities are difficult to deal with.

Of course, these informal systems are not the complete picture of high performance enterprises. As one participant noted, *"Good partnership is not a substitute for good business sense."* These informal structures must be matched, reinforced, and supported with formal structures, all of which must be enacted through individual behaviors in order to achieve the desired outcomes.

Formal Structures

The formal structures govern transactions within and between organizations in the enterprise. Holistically optimizing the formal structures across the enterprise is an opportunity to gain efficiency by standardizing transactions. Formal structures are primarily focused around managing "knowns." Knowns include things that can be articulated and planned for. The three formal structures identified in the cases studied are: balanced risk through work share and teaming arrangements, common contract structure, and standardized program management practices. These are show in Figure 9 and then discussed.

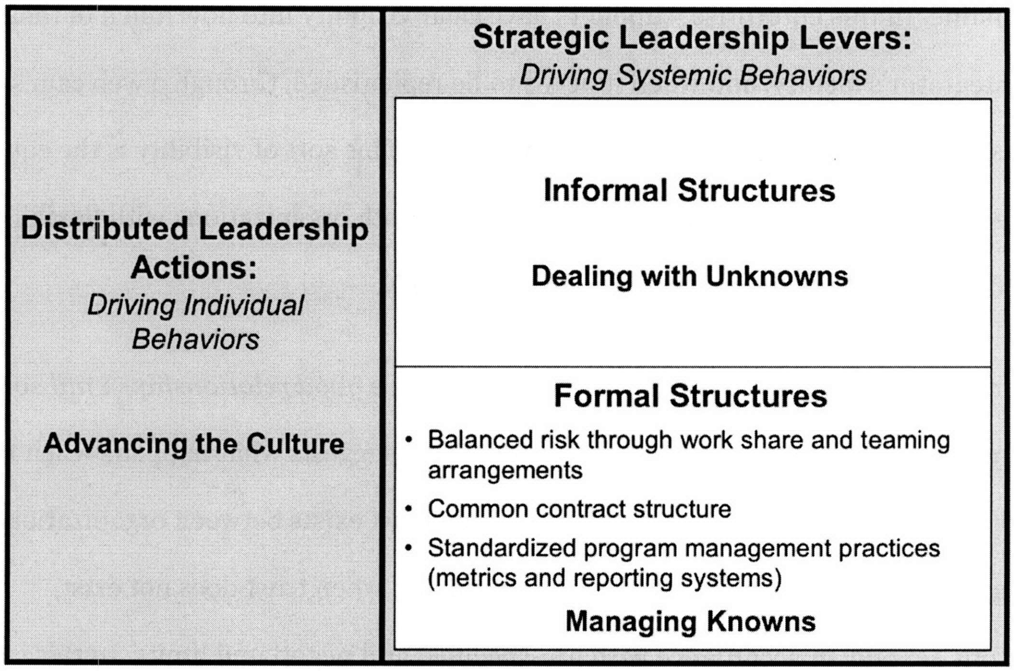

Figure 9. Elements of Formal Structures

<u>**Balanced Risk Through Work Share and Teaming Arrangements**</u> is the first formal structure. Work share and teaming arrangements specify how work will be divided up among major players in an enterprise. Decisions related to work share are based on competencies, expertise, and willingness to invest. Risk associated with technology development, financial investment, or schedule can be distributed among organizations. Teaming arrangements are one mechanism to balance risk between organizations by articulating work share agreements. Balancing risk may not mean equal risk for all organizations. Balancing risk means the level of risk each organization accepts is commensurate to their contributions to the enterprise. Balancing risk is an important step in creating an aligned value proposition for the enterprise where each organization's interests and contributions are known and taken into consideration. Formal teaming arrangements that specify work share allocation can prevent conflict over the course of the program.

Two of the programs studied provide contrasting examples of this. In one case, the teaming structure was worked out before the contracts between the parties were negotiated. The subsequent negotiations went very smoothly and the working relationships between the organizations were already under development when the actual contracts were signed, based on the upfront agreement of the role for each organization in the enterprise. In the other program, the work share distribution was decided as part of the contract negotiation. The contract took longer to negotiate and the working relationships were much slower to develop. Additionally, the development of the working relationships was hindered by the drawn out contract negotiations.

Another example of balancing the risk among organizations is the distribution of design authority, or the ownership of the design, including ability to change it. When design authority is centralized, the risk is also largely centralized. Distributed, shared design authority provides incentive for organizations to take on more risk. When an organization owns the design of their portion of the system, they have more flexibility in terms of use of materials, manufacturing processes, and suppliers. They can use this to their advantage to reduce the cost of producing their components. In one case, a supplier, who had the design authority and was working to a performance specification, changed a component in their subassembly in order to reduce cost. This is fine as long as they maintain the "form, fit, and function" of their subassembly, as it was described, so that there are no integration issues. As an added benefit, the new component they incorporated was not only less expensive, but was also better performing. As a result, they were not only able to reduce their cost, but they improved the system performance. This is the best of all cases where everyone benefits. An organization that maintains design authority also may have the ability to use the design for other applications. To gain these opportunities, organizations are frequently willing to take on additional risk. Balancing risk through teaming arrangements requires ensuring that no organization in the enterprise feels that they are being taken advantage of. When the benefits for each organization are aligned with their respective investments across the program, the players will be more willing to actively engage in the enterprise and more willing to develop and share common goals.

Common Contract Structure means that the contract structure used between the system integrator and their suppliers is the same as the contract structure between the integrator and the customer. Even though these different contracts do not cover the same scope of work, using the same structure aligns the incentives between the organizations. For example, a “cost plus” contract, or a contract that pays for the cost of the system plus a fixed percentage for profit, drives different behaviors than a fixed price contract. With a cost plus contract, there is motivation to incorporate changes from the customer, and there is incentive to take on greater risk in terms of schedule or technology, under the assurance that the costs will be covered. But, there is not an obvious incentive to reduce costs (unless there is a cap on the cost). With a fixed price contract, there is less incentive to take on risk, and there is less incentive to incorporate externally imposed changes to the system that would increase the cost. But, there is incentive to reduce costs in order to increase profit margin. Obviously, if the customer and system integrator have a cost plus contract, but the integrator and their suppliers have fixed price contracts, there is more opportunity for a misalignment of incentives between the organizations in the enterprise. A misalignment of incentives can cause locally optimizing behaviors that are sub-optimal or even detrimental to the overall enterprise performance.

In the programs studied, there were several examples of using a common contract structure mirrored throughout the enterprise as a mechanism to create a single, aligned incentive structure for the enterprise. In one case, for a more mature system, fixed price contracts were used throughout the enterprise. In other cases, for less mature systems, the contract mechanism was a long-term price commitment curve incorporating improvement such that the price decreased over time as the number of units produced increased (similar to a production learning curve). In another case, the contract structure was multi-year, creating the security of a long-term engagement. The various contract structures were selected based on the maturity of the system, the amount of new technology development, the schedule, and other relevant concerns. But, in each case where the contract structure was mirrored throughout the program, a single incentive system drove enterprise behavior.

Standardized Program Management Practices is the final element of formal structures. Not only within one organization, but using standardized program management approaches throughout the enterprise creates a single progress reporting and measurement system. It creates a single risk management system and a standardized meeting process, and in general it reduces the frictions associated with transferring program management information among and within organizations in the enterprise. One of the distributed leadership actions is personal accountability for plans and outcomes as a driver of individual behavior. Standardized program management practices go hand in hand with this personal accountability. Together they ensure both plans and outcomes are managed in a common way across all organizations and at all levels in the enterprise.

Many of the programs studied had some degree of standardization of their program management practices. In some cases, the standardization was a formal selection and deployment of best practices, followed by assessment of how completely a program had implemented them. The rigor associated with this identification, deployment, and assessment process ensures organizational learning. Barriers to communication often limit learning to the set of people directly involved (Kanter, 1994), but the formal process of identifying and implementing best practices is one way to ease the communication barriers and more broadly deploy the standard practices.

In addition to learning within an organization, standardizing program management practices is a way to transfer knowledge between organizations. It is also a way to convert tacit knowledge into explicit knowledge via a program management model and then back into tacit knowledge via socialization (Berman *et al.*, 2002; Nonaka, 1994). Standardizing program management practices throughout the enterprise establishes a smooth way to transfer knowledge between organizations. This can lead the way for interorganizational learning. Interorganizational learning is achieved by transferring existing knowledge from one organization to another, as well as by creating new knowledge through interaction among the organizations (Larsson et al., 1998). Beyond reducing the friction of transferring knowledge within the enterprise, which lowers the cost of each interaction, a structure that promotes interorganizational learning can provide even greater benefit to the enterprise. Interorganizational learning is the mechanism through which history, lessons learned, and experience are captured, creating a memory for the enterprise (Levitt & March, 1988).

These formal structures specify the way work is divided up among partnering organizations through specific roles and the way coordination is achieved among them (Kumar & van Dissel, 1996). Coordination includes protocols and decision mechanisms to achieve concerted action between interdependent units (Scott, 1992; Thompson, 1967). The division of work share, the balance of risk, the alignment of incentives, and the standardization of program management practices all contribute to reducing the friction and the variation in transactions in the enterprise. These structures are aimed at managing known aspects of the enterprise. The more smoothly they work, the more smoothly interactions in the enterprise work.

Discussion

Performance of aerospace programs is an important concern from many perspectives. At the simplest level, successful programs lead to successful companies; this is important for corporate executives, program managers, and all employees of an organization. Corporate results are also important to shareholders. On the defense side of the industry, as U.S. citizens we are interested in the performance of our programs as it relates to how efficiently our taxpayer dollars are utilized. As air travel passengers, we are concerned with the success of programs in sustaining high quality products, nearly impeccable safety records, and reasonable ticket prices. As academics, the performance of aerospace programs is a specific instance of a more general phenomenon, namely the performance of interorganizational network enterprises with distributed responsibility and leadership.

To relate the framework back to program performance, I returned to the raw data for each case study. I identified whether there was or was not evidence of each element in the case based on the data. This is a simplistic first cut but it provides some insight into the relationship between the elements and program record. It is important to reiterate that my data set is limited, and as a result, I fully acknowledge that evidence from my data set does not indicate prevalence of the practice throughout the enterprise. This analysis suggests a relationship that requires additional work to verify. Table 14 below shows how many programs in each category of program record exhibited each element of the framework. The Best in Class enterprises studied were proficient in all sections of the framework. They exhibited many, if not all of the individual elements, in one form or another. The Not on Track category exhibited only a couple, if any, of the elements. The middle category between Best in Class and Not on Track represents the largest portion of programs studied (those identified as Successful or Mixed Record), and there is substantial scatter in the evidence of practices in these enterprises. This group of programs is the most typical of the aerospace industry.

It is worth mentioning that the highest numbers in this middle column (10/12 and 11/12) are related to balancing risk between organizations and managing the interdependencies between organizations through boundary spanning within the enterprise. Because of the highly interdependent nature of organizations involved in aerospace programs, this is not surprising. It is also worth noting that the lowest numbers in this column (2/12 and 3/12) are both informal structures. This suggests that the lower performing programs focused on the formal, explicit elements, often taking for granted the underlying implicit structures and behaviors.

Table 14. Evidence of Best Practices Related to Program Record

0 – 25% 26 – 74 % 75 – 100 %	**Best In Class** (number observed/ number studied)	**Successful & Mixed Record**	**Not On Track**
Boundary spanning activity across organizations in the enterprise	5/5	10/12	0/2
Developing and utilizing a social network	4/5	6/12	0/2
Developing and sustaining extensive customer interaction	5/5	5/12	0/2
Fostering and maintaining personal accountability of plans and outcomes	5/5	8/12	1/2
Boundary spanning activity with the enterprise environment	4/5	6/12	1/2
Encouragement for open information sharing	5/5	3/12	0/2
Veteran core group to institutionalize behavior	5/5	2/12	0/2
Balanced risk through work share and teaming arrangements	5/5	11/12	0/2
Common contract structure	5/5	7/12	0/2
Standardized program management practices (metrics and reporting systems)	5/5	5/12	0/2

Summary

Based on the previous analysis of the case study benchmarking data, the meta-organization of the framework and the elements included in each section distinguish between high and low performing enterprises. The framework presented identifies a useful structure for the subcategories of data gathered, morphing them from interesting observations into applicable best practices. Based on the cases studied, to achieve high enterprise performance individual behaviors must be balanced with the formal and informal structures driving systemic behaviors. Together, the framework is a holistic representation of factors that contribute to enterprise performance.

Chapter 6

Implications of an Enterprise Architecture

Introduction

One way to characterize the framework emerging from this work is as an enterprise architecture. Generally, an architectural design specifies a combination of form and function from various perspectives. In the case of a building or structure, examples of different perspectives and their representations include a scaled model to represent the external form and aesthetics, floor plans to represent the internal functionality, blueprints to specify the operational plans for construction, and interior décor material samples to represent forms of materials that will be used. In a similar way, a system architectural design relates system objectives to outcomes by specifying the relationships between structural and functional elements (Rechtin & Maier, 1997). In the case of a social system, such as an enterprise, the most basic elements are individuals. Individuals form structured teams and organizations, which are also elements of an enterprise. The organized structures as well as the behaviors of enterprise elements both contribute to the collective outcomes of the enterprise. Like an architectural design for a social system, the framework described gives explicit consideration to the balance of structures and behaviors to achieve enterprise performance.

Considering this framework as an enterprise architecture is appealing for several reasons, but it also brings with it implications and caveats, that need to be thought through. Just as with the building example, an architectural design provides simplified, common representations that can be used for decision-making. The representations are simple enough for the design to be viewed holistically, but they include the relevant details so that ramifications of decisions are apparent. Developing an architecture for a complex system is crucial to the design process. The number of components and functional requirements for such systems are often numerous and beyond the cognitive limits of any one decision-maker. As a result, without the aid of good architectural representations, decisions get made with limited information and limited understanding of the system-wide consequences. This often means the difference between locally optimal decisions and system-optimal decisions. It is well established by game theory that individually optimized behavior does not necessarily result in optimized collective outcomes, as Merrill Flood and Melvin Dresher have shown with their Prisoner's Dilemma game (Ormerod, 2005). Enterprises are so large and complex that they cannot afford to have many individually localized optimizations; achieving high performance for the total enterprise requires a system-optimal approach. For this reason, having good architectural representations of the enterprise is an appealing goal.

Systems are characterized by having components that work together in such a way that they deliver performance greater than the sum of the individual components. The components are complementary; changes in one affect changes in the others. This is the nature of systems, and it is often taken for granted. The discipline of systems engineering has grown largely to deal with managing these issues during conception, design, and implementation of physical systems. The system architecture is a critical aspect for identifying the relationships between complementary components. For organizational systems, individuals' efforts are combined and focused by the imposition of various structures setting expectation and reinforcement of various behaviors.

Among these structures and behaviors many complementarities exist. At the organizational level, they are often difficult to untangle and are obscured by the limited purview of individual leaders and managers. At the enterprise level, this problem grows significantly with the introduction of organizational boundaries. Effects of structures and behaviors that are difficult to isolate in one organization are nearly impossible to tease out across enterprise relationships. Luckily, an enterprise architecture can help. A good enterprise architecture simplifies the complexity of the enterprise, identifies the key drivers of enterprise performance, and maintains the relationships between structures and behaviors such that complementarities can be understood. I propose that the framework developed in this work does just that.

There are some real limitations to the value of an enterprise architecture. Simply by using the description "architecture," it is implied that there is an *a priori* design of the enterprise. In practice, there is rarely a complete enterprise design in place before the enterprise is operating. More realistically, enterprises evolve, sometimes with a specific direction in mind, and sometimes in response to either external or internal pressures. Because of this evolution, any enterprise architecture developed empirically cannot represent an *a priori* design. In fact the framework developed in this work is clearly of this variety. First, it is a hybrid of several real world enterprises and, second, the elements of the architecture often developed organically within the enterprises, that is, they were not specific strategies from the outset. That being said, it is still interesting to think about the implications of using this (or any other) enterprise architecture as an *a priori* design for enterprise performance. Some of these implications from this framework will be discussed in the following section.

Enterprise Architecture

To review, the framework presented previously is shown in Figure 10. In this framework, the formal structures combine with the informal structures, which are supported and enacted by the distributed leadership actions. As a complete set, the elements together identify essential drivers of both individual and systemic behaviors. The architecture accounts for both structures and behaviors of the enterprise as they relate to achieving superior performance.

Distributed Leadership Actions:
Driving Individual Behaviors

- Boundary spanning activity across organizations in the enterprise
- Developing and utilizing a social network
- Developing and sustaining extensive customer interaction
- Fostering and maintaining personal accountability of plans and outcomes

Advancing the Culture

Strategic Leadership Levers:
Driving Systemic Behaviors

Informal Structures

- Boundary spanning activity with the enterprise environment
- Encouragement for open information sharing
- Veteran core group to institutionalize behavior

Dealing with Unknowns

Formal Structures

- Balanced risk through work share and teaming arrangements
- Common contract structure
- Standardized program management practices (metrics and reporting systems)

Managing Knowns

Figure 10. Framework for High Performance Enterprises

Recall that in the identification of the elements of the framework, specific outcomes were established for each element. Although those particular outcomes are still relevant, what is more important from an architecture standpoint is that the organization of this framework identifies complementarities between individual elements, namely within the sections and between the sections themselves, as they relate to enterprise performance. Because of this complementary nature, the specific outcomes of each element will not be rehashed, but the outcomes related to sets of elements in each section will be explored further.

Informal Structures, Effectiveness, and Flexibility

Just as the different elements of the framework are sorted into the distinct sections, each of these sections is in turn related to a specific aspect of enterprise performance. The informal structures are related to the *effectiveness of outcome* for the enterprise. The ability to manage unknown events and circumstances relates specifically to how effective the enterprise is. Programs are sufficiently large and complex that not everything can be known at the outset; this is appropriately planned for, but not even all of the unknowns can be anticipated. It is the uncertainty of the unknowns that is difficult to manage *a priori*, but in order for a program to be truly effective, they have to appropriately deal with these unknowns when they become certainties. Even if a program is able to plan and execute every single detail of what is known about the effort, they will not be effective. This is because it is simply impossible to know all the details of the program from the outset. The plan, execute, outcome model fails when what is known (and therefore what can be planned) is only a fraction of the total of what needs to be known to succeed. This is the case with aerospace programs; it is also the case with any enterprise developing a complex system. The informal structures provide an enterprise capability to integrate efforts productively; the stronger they are, the more tightly the enterprise can integrate, with fewer crevasses for surprises, wasted effort, lack of communication and coordination, or others, to hide or fall into.

Flexibility can be defined as the ability to adapt or change in response to different circumstances without severe time, cost, or performance penalties. Interorganizational structures are flexible and responsive to change (Hirschhorn & Gilmore, 1992). It is the informal structures in this architecture that are related to these properties of flexibility and responsiveness. This is in part because informal structures facilitate information flows for management coordination and control (Daft & Lengel, 1986) as well as lateral information flows (Scott, 1992). These informal structures essentially regulate the flow of information throughout the enterprise. When they are strong and working well, information flow is open and unimpeded. Information can be found and transferred in a timely manner, such that it does not expire before it is used. This alone prevents substantial rework of relocating and retransferring an update to previous information because it became obsolete before it was acted upon.

X-35: A Flexible Enterprise

An interesting example of enterprise flexibility occurred on the X-35 program. This competition was a winner-take-all game for a contract of unprecedented magnitude: hundreds of billions of dollars, over decades, to deliver thousands of aircraft. The X-35, developed by a Lockheed Martin led team, was competing against the X-32, developed by Boeing, as demonstration aircraft for the Joint Strike Fighter (JSF). Near the end of the competition, just before the completion of the test flights, it was apparent that both competitors had developed technically feasible systems. Boeing officials were touting the vast talent base they had gained by acquiring McDonnell Douglas and North American Rockwell, their past performance delivering other programs, and the fact that their test plane had flown exactly twice as many times as the Lockheed Martin version (Iannotta, October 2001). No one knew what criteria the competition was going to be decided on. The Lockheed Martin team had watched their competitor closely though, and at the very end of the flight test program, they decided to pursue a unique demonstration above and beyond what was required. "Lockheed plans a final dramatic display, a bid for the history books and bait for the huge government contract. In a test flight Lockheed dubs Mission X, its fighter takes off in less than 500 feet, then goes supersonic and lands vertically. Since the Harrier [the operational vertical landing fighter that the JSF will replace] is subsonic, the maneuver is a milestone in aviation history and a direct hit on Boeing's need to strip off parts for vertical landing and reinstall them for supersonic flight" (Jorgensen, 2003).[5]

The Lockheed leadership remained externally focused and proactively acted to attempt the Mission X demonstration flight as a way to improve their chances in the competition. In order to do this, the coordination among organizations required open information sharing for rapid problem solving and troubleshooting. The X-35B successfully completed two Mission X flights on July 20 and 26, 2001, the first by a U.S. Marine Corp test pilot and the second by a BAE Systems test pilot (Lockheed Martin, 2001). The fact that it was not even a Lockheed Martin test pilot who flew either of these historic flights is a testament to the high level of interorganizational trust that was embedded in this program. Although it is unclear exactly how much the Mission X flights played into the final decision of who won the competition (Iannotta, October 2001), it is a good example of how the set of informal structures in the X-35 program provided the program with the flexibility required to update their strategy near the end of the competition and effectively win.

Formal Structures, Efficiency, and Agility

Formal structures are related to the *efficiency of execution*. The formal structures standardize the interactions in the enterprise such that transaction costs are reduced. The more repeated and standard transactions are, the more efficient they can become (Williamson, 1981). The more broadly standard formal structures extend in the enterprise, the greater efficiency can be achieved. Formal structures in enterprises are frequently associated with bureaucratic procedures, documentation, or checks and balances. More generally, the formal structures involve information and knowledge that are explicit and can be codified. Lack of standardization

[5] In order to convert their demonstration vehicle for vertical landing, Boeing had to strip off parts to keep the aircraft weight down. This was acceptable within the requirements of the flight demonstrations.

in these structures causes a great amount of friction in enterprise execution. As a small example, consider the case where two organizations share data on a weekly basis. If the processes for collecting this data or the systems it is stored in are not standardized between the organizations, the data will have to be translated before it can be shared. For the sake of argument, say this translation takes an hour. Over the duration of a program, roughly 8 years, that is approximately 400 hours of translation that has to occur. That is two person-months that is eaten away with data translation. This is a simplistic, but illustrative, example of how even small transaction costs have a significant impact on total enterprise performance. When there is little to no friction in enterprise transactions, the enterprise can act more nimbly and respond without getting delayed and hung up on these sorts of non-value adding activities. In today's age of business transparency and accountability, the requirements for documentation and rigor in measurement and management are increasing. Reducing the enterprise friction by standardizing the formal structures is a critical aspect to achieving efficient operations.

Furthermore, efficiency gives the enterprise agility. *Agility* can be defined as the capacity and capability to act quickly and easily, in the current situation. This notion aligns with the benefits seen from implementation of continuous improvement philosophies like the Toyota Production System or Lean across an enterprise (Murman et al., 2002). Milgrom and Roberts (1990) argue it is by taking advantage of complementarities that modern manufacturing firms have achieved this sort of agility. "Flexible equipment and small batch sizes have been accompanied by other changes. Smaller batch sizes are directly associated with a shortening of production cycles and with reductions in work-in-process and finished goods inventories. Shorter product cycles in turn support speedier responses to demand fluctuations and lead to lower back orders" (Milgrom & Roberts, 1990, p. 512). They conclude that this clustering effect is not an accident, but rather "a result of the adoption by profit-maximizing firms of a coherent business strategy that exploits complementarities" (Milgrom & Roberts, 1990, p. 526). It has long been acknowledged that time can be a source of competitive advantage and an important strategy for many organizations (Dumaine, 1989). An agile enterprise has time on its side instead of racing to beat the clock.

JDAM: An Agile Enterprise

The Joint Direct Attack Munitions (JDAM) program is a good example of an agile enterprise. Suppliers have always been a critical part of the program, especially now during the production phase. During the following discussion, keep in mind that any change in the production system ripples throughout the entire supply chain, and any mismatches in capabilities between the suppliers and the integrator can wreak havoc on the program. When the second phase development contract was awarded in 1995, a production plan was laid out to begin in 1998, ramping up to approximately 5,000 units per year in 2001, and peaking at around 10,000 units per year in 2004. Production did begin in 1998 and it did ramp up fairly quickly, doubling production in each of the first three years, as expected. In 2001, with the events of September 11, the demand for JDAMs increased substantially and the production plan had to be updated. After the first three years of doubling production rates, production continued to double for the following three years as well, reaching approximately 10,000 units per year in 2001, around 20,000 units per year in 2002, and peaking at roughly 35,000 units per year in 2005 (Boeing, July 2005). Doubling production rates for the first six years of production is beyond the expected effects of manufacturing learning curves. This sharp increase in demand is reflected in the total acquisition objective, which increased from 88,000 to 236,000 total units through 2008 (Boeing, July 2005). Although it is not current, the following graph indicates the steep increase in production that occurred on this program between 2001 and 2005.

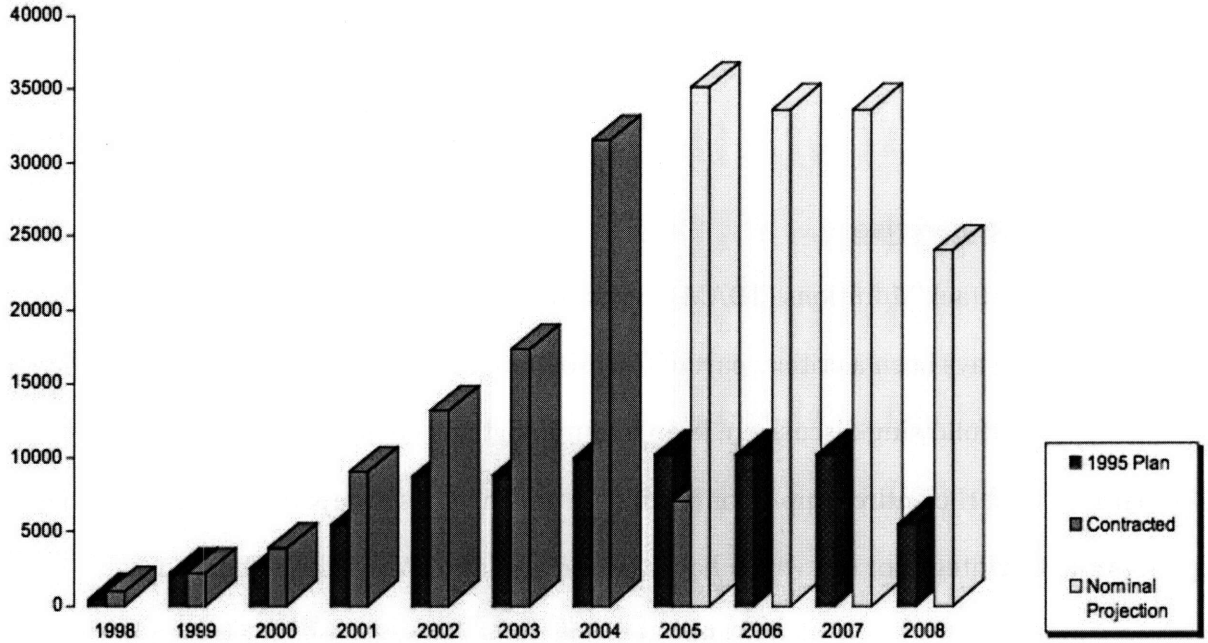

Figure 11. JDAM Production Rates as of 2004 (Darrow, March 23, 2004)

The JDAM enterprise acted together to quickly respond to this unexpected increase in demand, and they achieved impressive results. When the increase in demand became apparent, they realized they had a problem. Their existing production line had been sized for 1,600 units per month maximum, based on the original production forecasts. There was a choice to be made: either duplicate the existing line creating a total capacity of 3,200 units per month between the two lines, or create a single new line with a capacity of 3,000 units per month. Whichever option was selected, the transition had to be smooth, so there would be no bobbles in deliveries. Either of these changes would have substantial impact on the suppliers. After deciding the best option for all stakeholders would be to design a new line from scratch, Boeing led a team of program leadership, JDAM mechanics, suppliers, customers, and others to create and implement the design. Without disrupting on-going production, this team designed a new line to meet the expected production rate of 3,000 units per month in June 2003. This production line had to produce four variant models as well as accommodate warranty and service work (Darrow, March 23, 2004). Working together, the team created a solution to meet the increased demand and all other requirements. The new production line built on the already strong relationships in the enterprise and incorporated seamless transfer of information and parts between the suppliers and Boeing. The solution was also implemented quickly and without disruption to the on-going production. The new facility was up and running in six months (Darrow, March 23, 2004). Suppliers now deliver inventory to the Boeing assembly facility on a daily basis, and they are currently producing around 3,000 units per month. The increase in production rate that the JDAM program experienced is rather unique. The fact that they were able to meet it the demands without delay and deliver at the increased rate is impressive. Their quick response to this challenge is just one example of the agility of this enterprise.

Distributed Leadership, Empowered Workforce, and Robustness

Together, the formal and informal structures drive the systemic behaviors that lead to both the efficiency and effectiveness aspects of enterprise performance. Agility through efficient transactions and operations combined with flexibility gained from strong informal structures is a powerful combination. These structures create broad alignment across the senior leadership of organizations in the enterprise. This must be supported by deeper alignment within each organization in order to sustain the flexibility and agility achieved. The distributed leadership actions create deep alignment at all levels of the enterprise by driving individual behaviors.

The distributed leadership actions are critical in ensuring the vision is aligned throughout the enterprise and ensuring an *empowered workforce*. A system of distributed leadership reinforces desired individual behaviors, such as extensive customer interaction or accountability for plans and outcomes. Over time, this system enacts and shapes the culture of the enterprise, making the enterprise less fragile. Behaviors in the enterprise become taken for granted, without need for enforcement, because of the stability of the shared assumptions, values, and norms of the culture. Distributed leadership also creates goal congruency between individual actions and enterprise goals. As a system that enacts the culture and reinforces positive behaviors, distributed leadership results in an empowered workforce. Signs of an empowered workforce include a willingness to put the needs of the enterprise before individual needs, pride in the enterprise and the product delivered, and a personal sense of ownership for enterprise performance.

When an enterprise has a truly empowered workforce, it becomes *robust*. *Robustness* can be defined as the ability to withstand or overcome adverse circumstances to maintain performance. This robustness property allows the enterprise to sustain their superior performance over time. These distributed leadership elements also reduce how susceptible the enterprise is to individual influences, such as loss of an important leader or a new leader with a strong personal vision or style. Good program managers are often rotated through many different positions quite frequently (as often as every two years) as part of their professional development paths. While this is good for these individuals, in some cases leadership turnover can be detrimental to a program. Without the ability to overcome adverse or unexpected circumstances, enterprises breed skepticism about anything new or different. A negative experience when something does not go as expected leads to self-protectionism, risk adversity, and rigid reliance on what is known to work. On the other hand, robust enterprises, with empowered workforces and unified visions, directly support the flexibility and agility discussed previously.

<u>F/A-18E/F: A Robust Enterprise</u>

The robustness of the F/A-18E/F enterprise developed early during the concept exploration phase of the program. As has been mentioned previously, the Super Hornet program began during a tumultuous time for Naval aviation, following the cancellation of the A-12. Additionally, despite the technical successes of previous Hornet models, there was a long history of strained relationships between then-McDonnell Douglas and Northrop Grumman. The basis for the first F/A-18 was a Northrop Grumman design, the YF-17. In the 1970s when the Navy needed a replacement for their F-14s, Northrop wanted to sell them their design, but they had no experience developing aircraft for the carrier environment. They agreed to team with then-McDonnell Douglas to market the plane to the Navy. In the agreement, Northrop Grumman would be the "principal subcontractor" to McDonnell Douglas, and they would have a roughly 60/40 production split with the majority of the work and the final assembly done by McDonnell Douglas. The other part of the agreement was that Northrop Grumman could market a land version of the aircraft for other customers (including international), and for this version, the F-18L as it was known, the roles of the two organizations would be reversed (Baugher, 2000). As it turns out, not a single F -18L was ever sold. The F/A-18 series has been a success for the Navy and Boeing continues to sell them internationally. On the Northrop Grumman side, as long as people remember the YF-17 and the F-18L, there is some suspicion that Boeing "stole" their design because of the way events have unfolded. As a result of this history, during both the F/A-18A/B and C/D programs, relationships between Northrop Grumman and McDonnell Douglas were not strong. In light of the way the F/A-18E/F program was initiated, McDonnell Douglas, Northrop Grumman, and the Navy all had to agree to change the way they were doing business.

All of this back-story is setup for how the Super Hornet program became a robust enterprise. In 1992, twelve system concepts were evaluated to consider a spectrum of affordability and technical mission effectiveness. These twelve concepts spanned from most affordable and least technically capable to most capable and most expensive. The final selection was a middle of the road configuration with middle of the road engines. This was a conscious decision to hold the price down, knowing that this meant sacrificing additional signature reduction of the aircraft (although growth in this area was included), new cockpit displays, a different model concept than the existing 1-seat/2-seat configurations, and a bigger growth engine. After the concept was selected, initial system-level design began.

Despite best intentions, the E/F development started to go “out of the box” of their technical, cost, and schedule baselines in 1993. To remedy this situation, a period known as the 12 days in August was used to gather enterprise members together to understand the implications of development decisions and get the program back on track. This was an intense meeting and a significant influence on the dynamics of enterprise relationships. From that point forward, the program had a culture where the aircraft system was considered more important than any single stakeholder’s priorities. This “airplane is the boss” idea caught on and became part of the strong customer focus that the enterprise still holds today. In this case, it is not just the Navy acquisition customer, but in fact the warfighter customer that the entire enterprise is rallied around. This period in August 1993 was the origin of many of the practices used by the Super Hornet enterprise; it was also the beginning of what has become a very robust enterprise. Throughout the development phase of the program, there was not a single issue that got the program off-track; in fact, the program delivered to its original technical requirements, budget, and schedule baselines without updating them once during the eight years. This was accomplished not because everything went exactly as planned (it did not) but because the enterprise had developed a robustness that allowed it to perform regardless.

Putting It All Together

The implications of this enterprise architecture are significant. A select few drivers of individual and systemic behavior have been identified and related to enterprise outcomes. The elements are empirically based and were selected for their relationship to positive enterprise performance. Together, the elements lend themselves to an architectural design that incorporates both structure and behavior. The framework indicates not only the linkage from individual elements to particular outcomes, but of groups of elements to broader results. The result is a framework that identifies sets of complementary practices, and the relationship between these sets of practices, in a way that can have greater impact than a checklist of best practices. Perhaps most importantly, this architecture provides a holistic portrayal of the contributors to enterprise performance in a way that can be simply articulated and understood. The ability to simplify a complex problem in a way that new insights can be gained is an important contribution of this work.

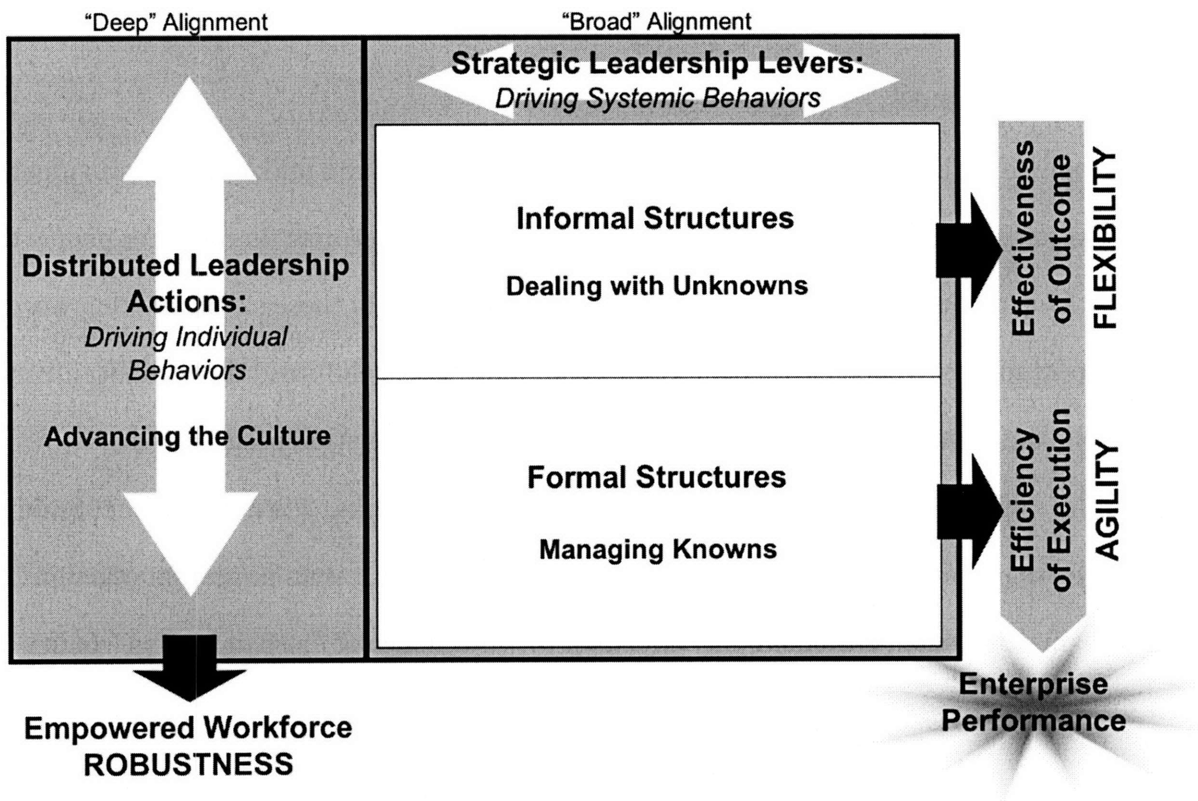

Figure 12. Implications for Enterprise Performance

Moving from Architecture to Practice

Now that the construction and potential implications of the framework are understood, there is a transition from the realm of the academic to the realm of the practitioner in order to operationalize the framework for any meaningful consequence. The elements in the framework are best practice program execution strategies. On the surface, they seem to be largely within the influence, if not the control, of the enterprise leadership. But, digging a little deeper, these practices have more profound ramifications.

This framework gives explicit consideration to many aspects of enterprise behavior that are generally not expressly acknowledged or articulated. The informal structures and some of the distributed leadership actions fall into this category. In order to bring these to light in practice, challenging changes are required in human resource, supplier management, systems engineering, and program management areas, just to consider a few.

Human Resources

Human resource practices include, for example, the development and utilization of individual social networks in creating a larger knowledge network for an enterprise. In order for people to want to develop and use their own networks, they need to be taught these skills, and they need to have opportunities to exercise them, and then they need to be reinforced through incentives. For example, organizations with formal or informal mentoring, rotation programs, or communities of practice, are providing ways to build social networks. It is not clear that building social networks is the motivation for starting these programs, but it is an important outcome. If it was recognized as such, one could only hope that the prevalence of these programs would increase.

Another important consequence for human resource practices is how individuals are recognized for their long-standing involvement with a particular program. It is critical to the ability to institutionalize enterprise culture, and in particular the trust-based relationships across organizational boundaries, to have a core group of enterprise veterans. This long tenure on a single program is not rewarded with current promotion systems. Akin to the idea of senior technical fellows who have chosen to specialize in a particular functional area (e.g. Mechanical Engineering), for large, important programs, which have a long duration, it is important to have "enterprise fellows." Senior technical fellows are rewarded for developing and deepening their expertise with a particular field in comparison with managers and executives who are often rewarded for developing a broader base of experiences. The idea of enterprise fellows would be to encourage developing a deeper range of experience on a particular program. However, current reward systems would have to be modified to accommodate, much less encourage, this.

Supplier Management

An important consideration in the area of supplier management is the various ways work share can be allocated among organizations. Often, the system integrator defines the system architecture, and then detailed design or production is divided up based on that architecture. In some cases, this may not be the best way to divide the work between organizations. Frequently, assuming a minimum level of technical capability, the best partner is the most willing partner. The ability and willingness to invest in the program, to develop competencies, and to work together may outweigh technical superiority of a particular design. One case identified willingness to work as a partner on the program as a selection criterion for their major suppliers. Timing is an important consideration as well. If willing partners are brought on board earlier enough, they can potentially influence the system architecture, by contributing their unique expertise for the benefit of the entire program. This was the case with the JDAM system. Supplier involvement early in the design phase led to a major architectural innovation, going from a partitioned architecture to a more integral architecture in order to reduce costs and improve design for manufacturing, among other benefits (Murman et al., 2002).

Systems Engineering

Several aspects of the framework developed in this work relate to managing interdependencies between organizations, or managing the relationship between the enterprise and its environment. Systems engineering has developed sophisticated and rigorous techniques to manage interfaces and boundaries in physical systems, even complex ones. Similar techniques and rigor are not applied to social systems. In some way, they might seem contrived and restrictive since humans are intelligent whereas physical system components are not, but in many ways they are even more crucial for an enterprise system. For one thing, components of an enterprise system, namely the behavior of organizations and individuals, can be influenced, but certainly cannot be constrained in the same way as the behavior of physical components. Managing these interdependencies is an even larger challenge than managing the interdependencies between components whose behavior is entirely predictable. Currently, these interdependencies are identified but they are managed with semi-structured or even ad hoc approaches. When specific attention is paid to them and they are actively managed, enterprise performance improves.

There is great opportunity to extend systems engineering from physical systems to the realm of socio-technical or even purely social systems to address challenges such as interdependencies across enterprise interfaces and boundaries. This idea is not original, and recently people are starting to explore this area more and more (Rechtin, 2000). In fact, college courses and professional programs are now emerging on the topic. The specific impact from this work is not to suggest a general expansion of systems engineering to enterprise systems, but more distinctly to point to the approaches systems engineering has for identifying and managing interdependencies between components and subsystems as a potential source of innovation when applied to social systems. This might be in the specification of interface standards between organizations or the jointly determined flow of information across organizational boundaries, as two examples. As evidenced in this work, relationships between people in the enterprise may be more important and more influential on enterprise performance than the interfaces between components in the physical systems. This significance is not reflected in the effort spent managing interfaces in the enterprise; perhaps this should be reconsidered.

Program Management

The implications of this work for the practice of program management are numerous, so rather than be exhaustive, this discussion will focus on only a couple of key points. First, program managers often cite having gained their expertise from on the job experience and mentoring

(Davidz, 2006). This reinforces the power of developing and using a social network, but it should raise the question, is the training provided to these managers inadequate, inappropriate, or ineffectual? An educated guess may be that this training tends to focus on the formal aspects of program management, while taking for granted the informal aspects. A review of the syllabus for the "Systems and Project Management" graduate course at MIT illustrates this point (de Weck, 2003). The course is broken into three modules: (1) methods and tools of project management (PERT, design structure matrices, system dynamics), (2) project preparation, selecting a product development process, and concurrent engineering infrastructures, and (3) project monitoring and risk management. There is no mention in the course material of any of the informal structures, or even the distributed leadership actions identified in this work. Recalling that it is the informal aspects that lead to effectiveness and flexibility, perhaps these are the program management skills that should be taught and exercised.

Another important ramification for program managers is not to underestimate the time it takes to develop these informal aspects. As one program manager conveyed, *"you can't manage what you don't know."* It should be clear that even if you manage everything you know, it would not be enough. Developing trust-based relationships, open information sharing, and proactively engaging the environment are all ways to learn more about what is unknown in order to prevent adverse affects. Another important role of the program manager is as the enabler and developer of their workforce. As was mentioned briefly before, the program manager acts as a catalyst and a role model for distributed leadership actions. Without the program manager exhibiting and reinforcing these behaviors, they will not gain critical mass to become self-reinforcing. The distributed leadership system is robust in many ways, but it is also fragile. All it takes is one negative experience and the behaviors will stop. The program manager must be consistent in leading by example for the desired behaviors in the enterprise.

A Note on Organizational Context

It would be inappropriate to end the section on moving from architecture into practice without some mention of organizational context. In the programs studied, the organizations in the enterprise were part of larger parent companies or institutions. These parent organizations provided a context for the execution of the program and the behaviors that were exhibited. With the original X-teams work, contextual enablers were identified (Ancona *et al.*, 2002). In this work, the context was described for each case study, but there has been no discussion of common contexts between either high or low performing programs. Without exhaustive analysis, it is suitable to make a few observations as a means of introducing the main caveat with using the framework in practice as an *a priori* designed enterprise architecture.

A first observation is that the elements of the framework developed organically in the enterprises they were studied. In general, they were not planned strategically from the outset. That being said, in many cases, sustaining the results by maintaining the elements was intentional. Another observation is that many of the elements developed with the help of a leader or small group of leaders recognized as being influential and visionary. The third observation is that the elements, generally speaking, evolved during or in response to a time of crisis for the enterprise. This crisis became the forcing function that instigated a different behavior or way of operating. This aligns with Schein's (1985) notion of how organizational cultures form as successful responses to crises. Finally, although the structures and behaviors identified in the framework were developed in the context just described, they were sustained even after that context changed. Exceptionally successful enterprises were able to sustain the elements of the framework and their outcomes, even after the influential leader had left or the crisis was abated. Additional research into how enterprises change would help address the questions of how these contextual factors impact the development or maintenance of the elements captured in the framework.

The important caveat for putting the framework into practice as an enterprise architecture is that context plays a role. Since there is no example of full-scale adoption of this framework, it is not clear what the specific contextual requirements may be. But, it is clear from the difference between the contexts in which the elements originally developed and were sustained that there are important considerations regarding context as the elements of the framework move from a theoretical construct to practical application.

Future Work

This work began with an interesting observed phenomenon that some aerospace programs are able to achieve extraordinary performance, while most cannot. Extraordinary in this context means meeting technical, cost, and schedule commitments simultaneously. The question of what distinguishes these exceptional programs from the majority of others was the focus of this study. Through an exploratory approach, an empirically based grounded theory has been developed. This section outlines a formal statement of the testable hypotheses from the theory generated. Since it is obvious the data collected cannot be used to both generate and test the theory, additional work will have to be done to test these hypotheses.

The hypotheses identified are not along the lines of experimental or statistical hypothesis testing where the definition includes null and alternative hypotheses. Rather, the hypotheses are stated as the predicted answer to a researchable question (Punch, 1998). The theory proposed previously explains why this particular answer is expected (Robson, 2002). Along those lines, while the theory building has managed to capture some of the complexities of the patterns of interrelationships between the elements of the framework, sharp delineations of the relationships have yet to be constructed. For this, different methods with a different level of precision and specificity must be used. A quantitative, cross-sectional study to establish correlation between defined variables would be a good place to start (Robson, 2002).

Before launching into the hypotheses, it is important to understand some assumptions and definitions. These have all been stated previously, but it is helpful to see them in a single place.

1. *Enterprise performance can be measured by a composite of both effectiveness and efficiency in meeting technical requirements and adherence to cost and schedule budgets.*
2. *Enterprise effectiveness is related to meeting commitments to the customers (either technical, cost, schedule or all).*
3. *Enterprise efficiency is related to the economical use of resources in order to meet those commitments.*
4. *Flexibility is the ability to adapt or to change in response to different circumstances without severe time, cost, or performance penalties.*
5. *Robustness is the ability to withstand or overcome adverse conditions in order to maintain performance.*
6. *Agility is the capacity and capability to act quickly and easily, in the current situation.*

Based on the analysis of the case study data and construction of the framework presented, several hypotheses have been identified. Although hypotheses could be generated for each specific element of the framework, those presented here focus on the complementary aspects of the elements and are at the level of the sections of the framework or the framework in its entirety.

H1a: Enterprises with stronger informal structures (external boundary spanning, open communication, institutionalizing mechanisms) will be more effective.

H1b: Enterprises with stronger informal structures (external boundary spanning, open communication, institutionalizing mechanisms) will be highly flexible.

H2a: Enterprises with more standardized formal structures (balanced risk, aligned incentives, and standardized practices) will be more efficient.

H2b: Enterprises with more standardized formal structures (balanced risk, aligned incentives, and standardized practices) will be highly agile.

H3a: Enterprises with distributed leadership systems (internal boundary spanning, use of social networks, customer interaction, personal accountability) will have a more empowered workforce.

H3b: Enterprises with distributed leadership systems (internal boundary spanning, use of social networks, customer interaction, personal accountability) will be highly robust.

H4: Enterprises with stronger informal structures, more standardized formal structures, and a system of distributed leadership will have higher enterprise performance.

Testing these hypotheses should involve quantitative social science approaches in order to establish correlation, significance, and perhaps even causation. Goals of quantitative studies are around precisely determining the relationships between well defined and understood categories (McCracken, 1988). Quantitative approaches are appropriate once categories have been identified and the relationships can be articulated and systematically explored. In order to begin thinking about using a quantitative approach, it is important to understand both the explanatory (independent) and outcome (dependent) variables. In each of the hypotheses identified, the outcome variables are enterprise effectiveness, efficiency, flexibility, agility, robustness, and enterprise performance respectively. The explanatory variables are the presence and strength of informal structures in H1a and H1b, the presence and standardization of formal structures in H2a and H2b, the presence of a distributed leadership system in H3a and H3b, and the presence of all of these aspects in H4.

With the variables defined, the next step would be to define operational measures for each variable. For the explanatory variables, a uniform benchmarking scale or maturity matrix could be used. For the outcome variables, the task is more difficult. Enterprise performance as an aggregate measure can be disputed, but the components, meeting technical requirements and adherence to cost and schedule budgets, can each be objectively determined. Enterprise effectiveness and efficiency are more fuzzy; empowered workforce, flexibility, agility, and robustness are fuzzier still. More work is required to precisely define each of these concepts in way that is consistently measurable.

Testing of the hypotheses is one way to refine and develop this proposed theory. Another direction for development of the theory is similar to the approach taken at the outset here. Although this study was not a direct replication of the X-teams work (Ancona *et al.*, 2002), it was a related extension, which provides insights to the team-level theory. In a similar fashion, replication of this study in a different type of enterprise (other than large engineering development programs) or in a different industry would provide useful refinement of the theory. "Given the relatively primitive stage of our understanding of what is happening in many real world situations, a sensible strategy, with some hope of progress in that understanding, would appear to be to capitalize on any studies where there are relatively strong findings giving support to a particular theory suggesting the operation of certain mechanisms in the contexts of the study" (Robson, 2002, p. 42). A series of concatenated studies is a good means of moving from grounded theory to more generic, overarching concepts, and finally to testable hypotheses (Stebbins, 2001). Using the X-teams theory as a foundation for theory development at the enterprise level is a first step in this regard.

An interesting question that this work raises is how X-enterprises relate to X-teams, specifically are X-enterprises made up of X-teams? This work abstracted the X-teams characteristics to the enterprise-level, considering the enterprise attributes as a whole, but it did not investigate characteristics of the constituent teams within the enterprise. This work set out to explore the existence of enterprise-level characteristics based on X-teams, and now that has been established, an interesting future direction would be to look into the relationship between the teams and enterprises exhibiting those characteristics.

Finally, in moving beyond testable hypotheses to a prescriptive formulation for enterprise performance, there is much opportunity for additional work. Some reflections on moving from theory to practice were offered previously, but these are just the tip of the iceberg in terms of verifying the efficacy of any prescriptive power of the theory. One of the most important aspects in this regard is the ability to generalize the mechanisms in the framework as they relate action to outcome. In order to do this, the context in which they work must be clearly understood. As mentioned previously, the best opportunity for this is additional work in enterprise change, which could shed light on the enabling context required for adoption of the framework.

Summary

Large-scale, complex engineering projects face significant technical challenges, but in many regards, this may be the easy part. They also face significant organizational and social challenges. These engineering systems are conceived, developed, and delivered by large enterprises consisting of many different organizations, hundreds of teams, and thousands of individuals. Today, there are high expectations for enterprises to execute these projects meeting challenging technical requirements, within tight cost and schedule constraints, yet many fail to do so. In the aerospace industry, only a few programs manage to achieve the exceptional success of meeting all of these goals simultaneously.

This work built on the theory of high performance, externally oriented X-teams (Ancona et al., 2002) to identify mechanisms that distinguish high performance enterprises. Based on an in-depth study of an enterprise that achieved this superior performance, the F/A-18E/F Super Hornet, the X-teams characteristics seemed to capture many, but not all of the attributes of the enterprise. Further study of an additional eighteen additional programs confirmed these preliminary results and refined an additional characteristic of high performance enterprises that was not evident at the team level. Inductive analysis of the data from all of the cases resulted in identification of ten mechanisms, which benchmarking evidence suggests distinguish high performance enterprises. These mechanisms were organized in a framework consisting of three sections of complementary elements. Observations of the outcomes of these elements were discussed as they related to enterprise performance. Finally, considering the framework as an enterprise architecture, some pragmatic implications were presented.

This work has contributed a framework for understanding performance of complex engineering programs. This framework is presented as a theory of high performance extended enterprises that is logically coherent, testable, and parsimonious, all elements of "good theory" (Eisenhardt, 1989). The framework considers both individual and systemic behaviors, as well as formal and informal structures enacted by enterprises. Each of these plays a distinct role in achieving enterprise performance. Moreover, the exceptional enterprises have succeeded, and the mediocre enterprises have failed, in recognizing the contributions each aspect makes to overall performance. Less successful enterprises tend to focus on the structures and behaviors required to keep the major stakeholders participating in the program; they tend to take for granted the underlying implicit and often tacit structure and behaviors which enable and support their desired performance. In contrast, high performance enterprises have strong informal structures, highly standardized formal structures, *and* a system of distributed leadership. The synergistic combination leads to a balance that poises enterprises to execute planned activities as well as leverage emergent opportunities and deal with unforeseen circumstances. For enterprises involved with large-scale complex engineering projects, these capabilities are a necessity in order to succeed, indeed maybe even to survive.

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Terms and Acronyms

A-	Attack-; designation for U.S. aircraft performing air-to-ground missions
A/B	Single seat/Two seat designation convention for aircraft (C/D and E/F models follow the same convention)
AIM	Air Intercept Missile
AESA	Active, Electronically Scanned Array
AFB	Air Force Base
AMF	Airborne, Maritime, Fixed
ATF	Advanced Tactical Fighter
Agility	(In an enterprise context) The capacity and capability to act quickly and easily, in the current situation
B-	Bomber-; designation for U.S. aircraft performing bombing missions
BMDO	Ballistic Missile Defense Organization (now MDA)
BMDS	Ballistic Missile Defense System
C-	Cargo-; designation for U.S. aircraft performing airlift missions
CDMA	Code Division Multiple Access
CONOPS	Concept of Operations
CTOL	Conventional Take-Off and Landing
CV	Carrier Variant
DAPP	Defense Acquisition Pilot Programs
DEMVAL	Demonstration and Validation
DoD	Department of Defense
DPRO	Defense Plant Representative Officer (now DCMA)
DCMA	Defense Contract Management Agency

E-	Electronic-; designation for U.S. aircraft performing electronic warfare missions
EKV	Exoatmospheric Kill Vehicle
EMD	Engineering and Manufacturing Development (now SDD)
ESS	Electronic Systems Sector
EVMS	Earned Value Management System
Enterprise	An interorganizational network working towards a common purpose of the development and delivery of a system, characterized by having distributed leadership and responsibilities and stakeholders with both common and diverse interests
Enterprise Effectiveness	Meeting commitments to the customers (either technical, cost, schedule or all)
Enterprise Efficiency	Economical use of resources in order to meet commitments to the customers
Enterprise Performance	Both effectiveness and efficiency in meeting technical requirements and adhering to cost budgets and schedule targets
F-	Fighter-; designation for U.S. aircraft performing air-to-air missions
FMS	Foreign Military Sales
FRP	Full Rate Production
Flexibility	(In an enterprise context) The ability to adapt or to change in response to different circumstances without severe time, cost, or performance penalties
GBI	Ground-Based Interceptor
GMD	Ground-based Midcourse Defense
GMR	Ground Mobile Radio
GPS	Global Positioning System
HMS	Handheld, Manpack, Small form fit
IDS	Integrated Defense Systems
IMP/IMS	Integrated Master Plan/Integrated Master Schedule
INS	Inertial Navigation System

IOC	Initial Operational Capability
IPT	Integrated Product Team
IR	Infrared
IRAD	Internal Research And Development
ISS	Integrated Systems Sector
JDAM	Joint Direct Attack Munition
LEAP	Light-weight ExoAtmospheric Projectile
LRIP	Low Rate Initial Production
LSI	Large Scale Integrator
JAST	Joint Advanced Strike Technology
JCR	Japan Cooperative Research
JET	JSF Effectiveness Team
JPEO	Joint Program Executive Office
JSF	Joint Strike Fighter
JTRS	Joint Tactical Radio System
LEO	Low Earth Orbit
LRU	Line-Replaceable Unit
MDA	Missile Defense Agency
MOU	Memorandum Of Understanding
NAVAIR	Naval Air Systems Command
NAVSEA	Naval Sea Systems Command
OPEVAL	Operational Evaluation
OSD	Office of the Secretary of Defense
PAT	Process Action Team
PBM	Process Based Management
PEP	Product Enhancement Program

PMCS	Programmable, Modular Communication System
P^3I	Pre-Planned Product Improvement
R&D	Research and Development
RAA	Responsibility, Authority, and Accountability
RAF	Royal Air Force
RF	Radio Frequency
RFP	Request For Proposal
Robustness	(In an enterprise context) The ability to withstand or overcome adverse conditions in order to maintain performance
SDD	System Design and Development
SFW	Sensor Fuzed Weapon
SM	Standard Missile
SOF	Special Operations Forces
SME	Subject Matter Expert
SPO	System Program Office
STOVL	Short Take-Off, Vertical Landing
UAE	United Arab Emirates
UAV	Unmanned Arial Vehicle
USAF	United States Air Force
USMC	United States Marine Corp
USN	United States Navy
WCMD	Wind-Corrected Munitions Dispenser
WSCD	Weapon System Concept Demonstration

Appendix A – F/A-18E/F Case Study Practices

These practices were collected as part of an in-depth case study of the program (Stanke, 2001). They were codified, reviewed by the organizations in the F/A-18E/F enterprise, and approved for public presentation to the Lean Aerospace Initiative community on September 22, 2000 (Stanke).

External Activity

Ambassadorship

- Leadership emphasis and insistence on developing and maintaining credibility to "keep the program sold" to DoD, Congress, and the general public
- High Performance Work Organization (HPWO) labor union-management partnerships used at Boeing with their union workforce to build trusting relationships
- Focus on marketing through the Hornet Industry Team (Boeing, Northrop Grumman, GE, and Raytheon) providing a single face to their customers

Scouting

- Multiple stakeholder involvement in pre-contract planning to bring in knowledge and expertise from the contractor and suppliers early in the program

Task Coordination

- Hornet Roadmap Team with members from the acquirer, end user and system developer jointly establish targets for improvement, sharing information about the potential of system enhancements and the costs and time associated with them
- Program management set internal expectations for the program based on early successes to create a reinforcing cycle

- The Super Hornet program incorporated 900 lessons learned from the previous Hornet program, managing the transition between programs

Extensive Ties

- Many functions were involved in the program definition process early on with equal voices to create common objectives and cooperative relationships
- The U.S. Navy and Boeing created strong ties between program management in order to establish and maintain program credibility, creating leadership alignment across the entire program, and alignment of leadership support within each of their own organizations
- Within Boeing, several groups were involved in creating program strategy, including Phantom Works, New Product Development, Production, and Business
- Boeing brought in a program manager from JDAM (another successful program) to share best practices when it had turn-over in the program management role

Expandable Structure

- "Suppliers as partners" philosophy treats suppliers as unique contributors to the program as opposed to a commodity
- Integrated Test Team to coordinate developer and customer testing into a single operation
- Alignment of the organizational structure to the work breakdown structure (WBS) of the system, allowing for integration of multi-functional teams within the program
- Suppliers, prime contractor, and customer all sharing a joint responsibility, "joint destiny" philosophy
- Organizational counterparts throughout the enterprise with active working relationships
- Flow down and roll-up of requirements, metrics, and responsibility, authority, and accountability (RAA) throughout the enterprise

- Long-term focus for the enterprise instead of getting distracted by short-term rewards

Flexible Membership

- Contractors supported the customer requirements definition process
- Following a "drop dead" philosophy by documenting each job so that someone else could come in and do the job effectively if the first person "dropped dead"; this facilitates the transition between layers in the enterprise
- The "best athlete" philosophy utilizes the best person for a task regardless of where in they are in the enterprise

Internal Mechanisms for Execution

Integrative Meetings

- Joint Configuration Change Board (JCCB) including representatives from all appropriate stakeholders (based on agenda), nominally, Northrop Grumman, Boeing, and the Navy
- Weekly program management reviews
- Every presentation at every meeting ends by having all participants ask for any help needed; this established a culture that it is acceptable to need help and important to ask for it; it was reinforced by management applying resources to provide help when it was requested

Transparent Decision-Making

- "Airplane is the boss" rule for making decisions; all stakeholders made decisions based on what was best for the airplane instead of what was in their individual best interest
- Each contract award fee period had unique criteria which were known up front so there was an obvious objective to work towards
- All trade-offs were evaluated against the "no growth" solution (no growth in terms of cost or weight)

- Cost Reduction Initiative criteria provided a consistent way to evaluate improvements/enhancements
- All metrics were collected weekly and shared throughout the program real-time to inform decisions

Scheduling Tools

- Earned Value tracking of both cost and schedule on a weekly basis so the information could be used for active management, as opposed to monthly or quarterly reporting
- "Perform to plan" philosophy to emphasize creating a good plan and then sticking to it

In addition to the practices and strategies that aligned well with the X-team characteristics, there were some additional practices identified which were outside the scope of the X-team characteristics. In general these additional practices were related to internal integration efforts of both the system and the enterprise.

Internal Integration

- Systems engineering principles were rigorously applied throughout system development, allowing for internal task coordination within the program
- A structured risk management process including systematic root cause analysis was shared throughout the enterprise enabling not only transparent decision-making but also transparent mitigation of risk and uncertainty in the program
- The enterprise agreed to support a common information infrastructure to share information in a timely fashion; they created a Hornet intranet and used common CAD modeling software regardless of what their own organizations supported

- Institutionalize best practices to sustain performance through transitions of personnel; the Super Hornet program management practices led to Boeing's corporate program management best practices

- Focusing on customer satisfaction; this is reflected in the "airplane is the boss" philosophy, but it provided the basis for the internal relationship building that occurred between the Navy and Boeing, Northrop Grumman, and others

- Open and honest communication; this is more than transparent decision-making; it became engrained in the culture and enabled people to express themselves in a constructive way

- Emphasis on teamwork held the enterprise together

- Management support mentality empowered individuals to effectively contribute to the enterprise; the program management envisioned the organization chart upside down, with themselves at the bottom supporting the program activity

- Leadership kept the program focused on staying within the "box" of technical and programmatic requirements

Appendix B – Research Protocol

Creating High Performance X-Enterprises

Research Protocol

The Lean Aerospace Initiative (LAI), based at the Massachusetts Institute of Technology (MIT), is a consortium of government, industry, organized labor, and academia in the aerospace industry interested in researching, developing, implementing, and accelerating enterprise transformation based on lean principles and practices.

You are asked to participate in a research study conducted by the Lean Aerospace Initiative at MIT. You were selected as a participant in this study because of your experience and your current position. You should read the information below, and ask questions about anything you do not understand, before deciding whether or not to participate.

Participation and Withdrawal

Your participation in this study is completely voluntary. If you choose to be in this study, you may subsequently withdraw from it at any time without penalty or consequences of any kind. The investigator may withdraw you from this research if circumstances arise which warrant doing so.

Purpose of the Study

Complex engineering systems are conceived, designed, and operated by enterprises. An enterprise can be generally defined as "One or more persons or organizations that have related activities, unified operation or common control, and a common business purpose." This definition includes enterprises focused on delivery of a product or service, called a program in the aerospace industry, and referred to here as either a program or a program enterprise. For systems with long histories, the program I am interested in studying is likely to be the development of a particular version of the system.

Deborah Ancona, Henrik Bresman, and Katrin Kaeufer constructed a theory of high performance teams, called X-teams. (MIT Sloan Management Review, Spring 2002) By studying teams of varying functions from a variety of industries, they identified five hallmark characteristics of the highest performing teams. These characteristics are: external activity, extensive external ties, expandable three-tier structure, flexible membership between tiers, and internal mechanisms for execution. Initial analysis suggests that the X-team concepts and practices may extend usefully to program enterprises, proposed as an X-enterprise theory.

There are two key questions in this research. First, does the X-teams theory apply to programs, and if so, how? This includes identifying how X-enterprises are similar to or differ from X-teams, what are the characteristics of X-enterprises, and what contextual factors are required for X-enterprises to function successfully? Second, are X-enterprise characteristics indicative of better program performance in the same way that X-team characteristics are indicative of team performance?

Procedures

Participants will be asked a series of questions in an interview (approximately 1-hour) about their program. The attached page includes questions that may be asked during the interview.

Potential Benefits

This work attempts to codify a structure for increasing performance of aerospace programs and extending traditional systems architecting and engineering to an entire enterprise. As such, this work contributes to the LAI body of knowledge. Your organization may benefit from interaction with LAI through early access to (or pre-release access to) these research results, and from the knowledge gained by discussions and interactions with the researchers. Various forms of feedback will be used to communicate research results with the host programs.

All results of this study will be vetted through the programs studied to ensure factual accuracy and non-inclusion of proprietary information. Results of this research will be published as part of a doctoral dissertation at MIT, and are likely to be published in scholarly journals and/or at professional conferences.

Payment for Participation

There is no payment for participation.

Confidentiality

Any information that is obtained in connection with this study that can be identified with you will remain confidential and will be disclosed only with your permission or as required by law. Data will be stored securely until research is complete, at which time any attributable data will be destroyed. Reported data will be non-attributable.

Identification of Investigators

If you have any questions or concerns about the research, please feel free to contact:

Ms. Alexis Stanke	Prof. John Carroll (faculty sponsor)
astanke@mit.edu	jcarroll@mit.edu
(617) 258-7984	(617) 253-2617

Rights of Research Subjects

You are not waiving any legal claims, rights or remedies because of your participation in this research study. If you feel you have been treated unfairly, or you have questions regarding your rights as a research subject, you may contact the Chairman of the Committee on the Use of Humans as Experimental Subjects, MIT, Room E23-230, 77 Massachusetts Ave, Cambridge, MA 02139, phone (617) 253-4909.

Signature of Research Subject

I understand the procedures described above. My questions have been answered to my satisfaction, and I agree to participate in this study. I have been given a copy of this form.

Printed Name

Date

Signature

Signature of Investigator

In my judgment the subject is voluntarily and knowingly giving informed consent and possesses the legal capacity to give informed consent to participate in this research study.

Printed Name

Date

Signature

Follow-up Information (Optional)

If needed, how might we contact you to clarify or check the accuracy of our notes on this interview? Please share an email address, phone number, or postal address that we could use to contact you.

Thank you for your participation in this research!

Interview Questions

The interview will begin with introductions, a short explanation of the topic and motivations for the research, and collection of biographical data that will be used to help sort and aggregate respondents. This will be followed by a series of questions and responses that will loosely follow the outline presented below. The interview will unfold as a semi-structured conversation covering the topics of interest instead of a more formal interaction.

1. Describe the program: Who is involved? How are people organized? How is work organized? How does the program fit within the larger context of your organization?

2. What sorts of things are done to ensure the program stays integrated and on-target in terms of technical and programmatic goals?

3. How do people typically interact with each other? Within your organization? With people on the program from other organizations?

4. What sorts of activities are you involved with or aware of that involve the program and people outside of the program? For example, what sort of interaction happens between the program and the leadership of your organization?

5. During the program or in preparation for the program, did you create a professional network of people that you can learn from and share experiences with? Describe how this network contributes to the work you do on the program. In what ways are your experiences with your network of people similar to or different from that of others on the program?

Appendix C – Aerospace Case Studies

These case summaries are meant to familiarize the reader with each program. The organization and timeframe studied is included in the title of each study. Each case will be briefly introduced to describe the purpose of the system, and then an abbreviated chronology of major program events is laid out covering the timeframe of the case study. Following the program history, some of the unique execution challenges, strategies, and accomplishments are described. These are certainly not exhaustive accounts of these programs, and therefore cannot reflect the performance of the programs. For the reader, the case descriptions provide a sample of the nature of the data collected from the case studies. They have been described here not to draw attention to particular circumstances or peculiarities in specific cases, but rather to highlight the challenges that face contemporary aerospace programs and to outline the strategies these programs use to tackle these challenges. The concrete examples provided in each case are representative of both demands on programs and the results they are able to achieve. The participants and organizations involved in this research graciously shared their experiences for the benefit of this study. I take full responsibility for any errors or shortcomings in the descriptions.

Aircraft and Engines

C-17 (1994-present)
Boeing Integrated Defense Systems, Long Beach, CA

C-17 Globemaster III is the newest cargo aircraft in the U.S. Air Force airlift inventory. The C-17 is used for delivery of cargo and troops as well as tactical airlift and airdrop missions. The C-17 is designed to airdrop 102 paratroopers and equipment or 170,900 pounds of payload (US Air Force, 2005a). As threats to the U.S. have changed, the equipment used to fight those threats has also evolved. In general, these changes have increased the air mobility requirements for large or heavy cargo (US Air Force, 2005a). The C-17 meets these needs with high reliability and low maintenance requirements. In addition to meeting the strict reliability and maintainability requirements, the C-17 has a cost-effective flight crew of only three people, a pilot, copilot, and loadmaster (Boeing, 2005b).

The C-17 is a large plane. It is 174 feet long with a nearly 170-foot wingspan. Despite its size, it is very nimble in operation. The C-17 can take off and land on runways as short as 3,000 feet and 90 feet wide. Even in these confined spaces, the C-17 can turn around in a three-point turn (US Air Force, 2005a). Additionally, C-17s have set 33 world records for their performance capabilities, more than any other airlifter (Boeing, 2005b). The C-17 program won the prestigious Collier trophy for achievement in aerospace in 1995, the Malcolm Baldridge National Quality Award in 1999, and the Boeing assembly facility was rated as one of *Industry Week's* Best Plants in 2002 for being one of the top ten in North America (Boeing, 2005b). These are only select highlights of the many accolades for the C-17 program.

Program History

Although the C-17 has a long and interesting history, dating back to the initial development in 1981, this case only considered the recent decades of the program since 1994. There was a major turning point in the 1993-94 timeframe when the program was nearly canceled due to technical problems, cost overruns, and schedule delays. This case study focuses on the program after the turn around. The first flight of the C-17 was in September 1991, so by 1994 the major development work was complete and the program was beginning the production phase.

Although the Air Force had planned to buy 120 aircraft, in January of 1994, as part of the program turn around, production was limited to 40 aircraft for a two-year probationary period to achieve performance, cost, and delivery targets (Jane's Information Group, 2005c). The C-17 first became operational in January 1995. In November 1995, the Air Force decided to buy the remaining 80 additional aircraft to meet the original plan. They awarded a multi-year contract in May 1996 for these 80 aircraft, sustaining production through 2004. To illustrate the turn around on the program, the first production aircraft in 1994 were late and had quality problems, but the 120th aircraft was delivered nearly six months ahead of schedule. In August 2002, a second multi-year contract for an additional 60 aircraft was announced, sustaining the production rate of 14 aircraft per year into 2008.

Program Execution

There were several important parts of the program turn around, from changes in leadership to changes in organizational structure, but two critical aspects were creation of a team-based culture and a shift to process based management. In 1993, the program environment was tenuous at best. Relationships between the Air Force, McDonnell Douglas (now Boeing), the Department of Defense (DoD), the unionized workforce in Long Beach where the plane is produced, and the Defense Plant Representative Officer (DPRO, now Defense Contract Management Agency, DCMA) were all strained and adversarial. Data and information were not shared across organizations, and in fact they were not always internally consistent. It was sometimes difficult to confirm metric results because data sources were not designated (Todd, 2005). Between 1991 and 1993 several audits were performed of the program by both internal and external groups; they consistently indicated the same results – the program was in trouble (Todd, 2005). The dire situation makes the subsequent turn around all the more impressive, but it also was the catalyst to make it happen. The C-17 would not be where it is today without the extreme wake-up call they received when the Air Force said they would only buy 40 aircraft if the program did not perform.

Starting with this turn around, there were joint customer/contractor efforts to restructure and recreate management systems used on the program. An explicit partnership between the Air

Force System Program Office (SPO), DPRO, and McDonnell Douglas was established to develop improved working relationships between the organizations. This partnership started with off-sites of the joint leadership team. These off-sites continue today, twice a year. Efforts were also made to repair the relationship with the unionized workforce in Long Beach by creating opportunities for skill development. This helped improve workmanship in assembly, reducing quality problems in production. Additionally, Integrated Product Teams (IPTs) were developed jointly between the SPO and McDonnell Douglas in early 1994, using common goals and metrics. An important sense of shared destiny led to goals that were flowed down through the entire program. All of these examples serve to provide a sense of how the team-based culture on the program got started. The teaming philosophy exists at all levels of the organization, from the leadership down. There was recognition by all involved that behaviors had to change. There was also recognition that the previous adversarial relationships were not headed in the right direction and that, in fact, to turn around this program, it would take not only one stakeholder pulling the program along, but all of them working together. This team-based culture is still an important underpinning of how the program operates today. Maintaining emphasis on relationships and communication reinforces the trust that has been established.

Another important aspect of the program turn around that is still in evidence today is Process Based Management (PBM). A standard way to manage and improve processes was put in place with closed-loop feedback systems. The process based management approach can be summed up in four bullets that appeared on a PowerPoint chart at the time (Todd, 2005).

- Cover Everything We Do
- Manage and Improve Through a Single Disciplined Approach
- Help Us Measure
- Empower Owners

The first bullet refers to having a complete and holistic model that represents all aspects of the C-17 program from design and production to management and enabling support processes. The second bullet is focused on a common way to manage processes on the program. The third bullet refers to using the PBM approach as a way to do work with checks and balances. The forth bullet speaks to the responsibility, accountability, and authority given to process owners to actually manage their areas. This required a shift in mindset away from the traditional functional managers (skill based) to managers of end-to-end processes.

To help define the C-17 process model, Process Action Teams (PATs) were deployed in all major disciplines to help identify common processes and metrics. The process model has been periodically updated since it was defined, and process based management is still an important management system on the program. PATs are also still used for process improvement efforts across the program.

The team-based culture and PBM remain two key enablers of the C-17 success. The success the program has been able to achieve has permeated the entire extended program. Boeing has acted as a mentor for suppliers. The C-17 program has serves as an example for other programs in the Air Force and other parts of Boeing. They have participated in development and deployment of best practice models. Most importantly the program leads by example. They continue to model the behaviors that have made them successful, promoting their adoption and reinforcing their institutionalization throughout the program.

F119 Engine for the F/A-22 (1991-present)
Pratt & Whitney, East Hartford, CT

See Chapter 3 beginning on page 60.

F-16E/F or Block 60 (2000-present)
Lockheed Martin Aeronautics, Fort Worth, TX

The F-16 has a long history dating back to the 1970s, including over 4,000 aircraft deliveries in over 110 different version to 24 countries (Lockheed Martin, 2005). Originally designed for the

U.S. Air Force, the F-16 is a multi-role fighter with proven affordability and performance. The latest development in the F-16 line is the Block 60 version for the United Arab Emirates (UAE) Air Force. Although many foreign customers have required specific tailoring of capability, the Block 60 effort represents significant development work. In fact, this new version is the largest single change to the plane since it's inception, as such, it warranted the designation of E/F to distinguish it from all previous F-16C/D versions. The last change in designation occurred in 1984 when Block 25 aircraft became C/D.

The Block 60 upgrades were developed exclusively for UAE, and they are currently the only customer of this version of the fighter. Named the Desert Falcon, the F-16E/F includes a new core avionics suite, including advanced radar and electronic warfare systems, a new cockpit layout, a digital fuel management system, a higher capacity environmental control system, a new air data system, and expanded digital flight control system above and beyond the capabilities of the latest U.S. F-16 aircraft (Jane's Information Group, 2005f).

The Block 60 development required approval from Congress, the U.S. Air Force, and the U.S. Navy; it has been quietly controversial since it will provide UAE with greater capability than the U.S. Air Force currently has in the domestic F-16 fleet. The U.S. has not pursued further development of the F-16 because they are bringing F/A-22s into operation, and they are developing the advanced F-35 Joint Strike Fighter (JSF). To be clear, both the F/A-22 and the F-35 are more capable than the most advanced F-16s operated by the U.S. Air Force, or the F-16E/F. The Block 60 radar and electronic warfare systems were particularly contentious, but in the end, it was not the technical factors that prevailed over approval of the development and sale to UAE. For example creating higher-level contacts between the U.S. and UAE militaries would enhance cooperative security in the Middle East. Taken together, the benefits to the U.S. outweighed the potential downsides of selling cutting edge technology (Dooley, 2004).

UAE, is a different customer than the U.S. military, or even other foreign customers. UAE is on the southern coast of the Arabian Gulf between Saudi Arabia and Oman. It is a relatively new country, formed in 1971 when the U.K. withdrew from the Middle East. As of 2003, it had the third largest petroleum reserves in the world and the fourth largest natural gas reserves. Natural resources and geographic location guide the country's foreign policy. "Emirates leaders and citizens alike understand the country's strategic significance and the importance of regional alliances and national defense" (Hehs, 2003b). UAE does not have a large industrial base to draw from, nor are they trying to develop one. As a result of their wealth of natural resources and the conflict in their surrounding region, they are skilled negotiators and focus on building strategic relationships. They were not interested in large offset agreements including development of aerospace production capability in their country as part of the aircraft acquisition, but they were interested in developing a stronger relationship with the U.S. government and the U.S. military in particular.

The Block 60 program includes development of the E/F aircraft, production, and delivery of 80 aircraft, 55 single-seat and 25 two-seaters. When the contract was signed in 2000, it was worth $6.4 billion. In addition to the direct economic impact, the program was estimated to provide 100,000 man-years (approximately 12,500 people over 8 years) worth of jobs for people in over 40 states (Lockheed Martin, March 5, 2000). The ramifications of this program spread much further than alliances with the U.S. military, they ripple throughout the nation. Another facet that makes the Block 60 program unique is the contracting approach. The UAE acquisition is a commercial contract directly between UAE and Lockheed Martin. Usually, sales of military technology to foreign customers go through a formal Foreign Military Sales (FMS) process. This contract bypassed that process and UAE negotiated a fixed price contract for development and production directly with the system integrator. This is somewhat risky for Lockheed Martin, but it is a strong incentive to keep costs under control.

Program History

In 1994, the UAE identified the need for 80 long-range strike fighters (Baugher, 2004). Lockheed Martin immediately responded and began developing a potential upgrade or modification to the existing F-16. UAE investigated the best fighters available, including the F-16, the Eurofighter, and the Rafale, and the Russian Su-37. They were selecting based on operational requirements, technical requirements, environmental requirements, political support, and technology releasability (Hehs, 2003b). After more than 90 evaluation flights in the F-16, spanning six years, UAE selected the F-16 on May 12, 1998.

After the selection announcement, the negotiation period of the sale began. It lasted a long 22 months. The negotiation period was complicated by the nature of the sale (not using the more standard FMS process) and the technology involved. There were numerous potential showstoppers including controversy of whether computer software codes would be released. Although many of the details of the deal remain classified, all issues were resolved to the satisfaction of all involved and the contract was signed on March 5, 2000.

In 2003, the Block 60 aircraft received the E/F designation, recognizing the major changes to structure, avionics, and propulsion. The first flight of a Block 60 aircraft was a F-16F on December 6, 2003 (Jane's Information Group, 2005f). Delivery was initially anticipated in 2004, but the first ten aircraft were not delivered until May 3, 2005. The aircraft is scheduled to be in production for UAE through 2007.

Program Execution

There were several unique aspects of this program that enabled execution. The first and most important of these is the nature of the relationship with the UAE customer. Lockheed Martin has a lot of experience dealing with foreign customers, but UAE is still different. As a customer, they were more focused on establishing trust and in the general nature of relationships than other customers have been. They wanted to be involved. They have participated on-site with the

Lockheed team since 2001. It was something of a cultural exchange, with Lockheed learning about the UAE culture and the UAE representatives learning as much about the status of the program and the capability of the aircraft as possible.

Another important aspect of the program is the emphasis on accountability. From the top down, there is a serious focus on personal accountability. This likely stems from the terms of the contract. In contrast to the focus on trust and involvement in learning and understanding the system, UAE negotiated harsh penalties in the contract. Lockheed Martin signed up for this contract with its fixed price and strict penalties because everything was clearly laid out up front, both in terms of technical and programmatic requirements. UAE wanted everything specified up front so they would know what they were getting, but once this was established, they also agreed to keep the requirements stable. This high level of stability is not there with the U.S. military customers. Stable requirements were also possible because, despite the many advances made with Block 60, the program largely involved mature technology. The nature of the contract created a reinforcing system between the requirements, the incentives, and the outcomes. It also created an environment focused on accountability and meeting commitments. Lockheed Martin extended this throughout the program by using a common fixed price contract structure with their suppliers and partners. This had the additional benefit of aligning the incentive system of the whole program.

Working with a new customer with a different type of contract required Lockheed Martin to reevaluate how they would execute the program, but it also allowed the flexibility to do things differently. Because it was not an FMS program, it was not constrained by U.S. military processes or requirements. That being said, Lockheed Martin's experience is almost exclusively with defense customers, so they did not throw out the way they know how to do business, but rather they rethought processes to determine if they were really contributing value to the UAE customer or not. Even though this is a commercial contract, they did not really adopt commercial practices as much as they streamlined the defense practices they were already very familiar with. The leadership of the program isolated the Block 60 team from the rest of the F-16 work and encouraged people to ask, *"Is this the right thing for us to do for this program?"* Common practices for the company were questioned in light of making the program successful. For example, they implemented a hand-off database to help with integration issues so that both sides of each hand-off have visibility and input into the process. They also created a process to use common desktop scheduling tools (e.g. MS Project) in a disciplined way so the data can be rolled up between teams instead of requiring people to translate the data into an additional tool.

F/A-18E/F (1992-present)
Boeing Integrated Defense Systems, St. Louis, MO

The F/A-18E/F Super Hornet is the newest fighter in the Navy inventory. The Super Hornet is the newest addition to the Hornet family that includes previous A/B and C/D versions. It was developed in the wake of the cancellation of the A-12 program, and at the time, it was the Navy's largest aircraft development program, so it essentially represented the future of naval aviation. Additionally, without this program, the Navy had no viable replacement for the F-14 or the older Hornets.

The E/F aircraft share 90 percent commonality in avionics and limited similarity in the airframe with the C/D versions. The Super Hornets are 25 percent larger, have a 40 percent increase in un-refueled range, 25 percent increase in payload, three times more bring-back ordnance (weight which can be landed with on an aircraft carrier), and five times greater survivability. So although the E/F was an upgrade to an existing platform, it was more like a new development in many regards.

The Super Hornet was developed and integrated by Boeing as the prime contractor to the Navy customer. Boeing makes approximately two-thirds of the aircraft and integrates the final system. Northrop Grumman is the principle subcontractor on the program; they make the aft third of the aircraft including where the engines fit into the plane. GE and Raytheon are also key players providing the engines and the radar respectively. There are also hundreds of suppliers involved with the program.

The Super Hornet is an all-weather, multi-role tactical aircraft. The capabilities of the F/A-18E/F cover the entire range of tactical missions, including air superiority, day/night strike with precision-guided weapons, fighter escort, close air support, suppression of enemy air defense, maritime strike, reconnaissance, forward air control, and aerial refueling (Boeing, 2005c). The newest development in the Super Hornet program is to develop the two-seat F version into the EA-18G, an electronic warfare aircraft, to replace the aging EA-6B (Jane's Information Group, 2005d).

By all regards the Super Hornet program is exceptional. "The F/A-18E/F acquisition program was an unparalleled success. The aircraft emerged from Engineering and Manufacturing Development meeting all of its performance requirements on cost, on schedule and 400 pounds under weight. All of this was verified in Operational Verification testing, the final exam, passing with flying colors receiving the highest possible endorsement" (US Navy Fact File, 2005a).

The cost per flight hour for a Super Hornet is 40 percent of that for a F-14 Tomcat, and the Super Hornet requires 75 percent fewer labor hours per flight hour for maintenance (US Navy Fact File, 2005a). The F/A-18E/F was also designed with growth in mind. New capabilities are typically incorporated into aircraft through upgraded electronic systems, but physical space is often the limiting factor in how many modifications can be incorporated into an existing airframe design. With this in mind, the Super Hornet includes 17 cubic feet of growth capacity for electronic systems (US Navy, 2005).

Program History

On January 7, 1991 the Navy's A-12 Avenger program was cancelled. At the time, this was the largest contract termination in Department of Defense (DoD) history (Pike, 2005). Although the program was cancelled because of technical problems and major cost and schedule overruns, the Navy still needed the attack capability of the aircraft as well as replacement for their aging fighters (the F-14 Tomcats as wells a older F/A-18 Hornets). An upgrade to the Hornet family was proposed as a feasible option in 1991. In June 1992, a $4.88 (FY92 dollars), 8-year Engineering and Manufacturing Development (EMD) contract was awarded to McDonnell Douglas (now Boeing) for the F/A-18E/F Super Hornet. This contract included seven flight test aircraft and three ground test articles.

The Super Hornet program has had exceptional success throughout the entire program, beginning with the first major design review in June 1994, when it was noted that the F/A-18E/F was satisfying or surpassing all timescale, cost, technical, reliability and maintainability requirements (Jane's Information Group, 2005d). Roll out of the first aircraft produced occurred September 18, 1995 with first flight on November 29, 1995.

The test program began in February 1996 and lasted for three years until April 1999. In the meantime, Low Rate Initial Production (LRIP) was approved to being in 1997 with eight E aircraft and four F aircraft in the first production lot. Operational Evaluation (OPEVAL) was completed in late 1999 with the results announced in February 2000. The Super Hornet received the highest rating possible in OPEVAL of being "operationally effective and suitable."

The first production delivery occurred in December 1998, more than one month ahead of schedule. Full rate production began in February 2000 as part of the first multi-year contract. In 2000, the first multi-year contract was approved for 222 aircraft over five years. In December

2003, a second multi-year contract was announced for 210 additional aircraft between 2005-2009.

While the E and F are in production, the EA-18G began development as early as 1995, but the technology was not demonstrated in flight until 2001. In early 2004, a five-year System Design and Development (SDD) contract was awarded for this modification.

The first operational squadron was stood up in the third quarter of 2000, and just two years later in July 2002 they received their first deployment. The Super Hornet saw its first combat experience in November 2002.

Program Execution

Several aspects of the execution of this program are discussed in other parts of this thesis, but there are a few highlights worth mentioning here. First, throughout the program there has been a strong emphasis on the customer relationship. From the initiation of the program, through current work, the customer relationship has always been paramount. In terms of the F/A-18E/F program the customer has always been the warfighter. The core Super Hornet team includes the Navy, Boeing, Northrop Grumman, Raytheon, and GE. The leadership of this core team has always been aligned in advocating as a single entity for the program. They have jointly maintained credibility of the program within DoD, and they have innovatively worked together providing impressive results for the customer.

An older example of this is the Integrated Test Team between the Navy and Boeing. Usually, the contractor and military acquisition customer have their own separate test programs. With the F/A-18E/F, they joined together to run a single EMD test program. By combining their test requirements, they reduced the total number of test flights they had to make. It did not matter if it was a Boeing pilot or a Navy pilot at the controls, they were all F/A-18E/F test pilots working towards common goals. Of course, this required open sharing of data and joint problem solving between the organizations. The point of test programs is to find issues with the design and discover the limits of the system; failures happen. It took courage in the leadership of Boeing to expose themselves to real-time criticism of the aircraft, and it took courage of the Navy leadership to ensure that they would help resolve problems instead of accusing and punishing the contractors. This strong sense of purpose for the warfighter customer is still pervasive today, many years after the EMD program and testing have been completed. In a recent program management meeting, a review of the working together principles of the program included emphasis on one team between the Navy and Boeing, showing direct linkage to providing "customer value."

Open information sharing is another important aspect of the Super Hornet program. Just as during EMD testing, real-time sharing of information between organizations enables execution and has created a "no surprises" culture in the enterprise. Because this program was initiated just after the cancellation of the A-12, open sharing was practically required in order to ensure sufficient transparency into program execution. This quickly enabled many reinforcing behaviors on the program that led to success upon success. This history of meeting or exceeding expectations has been a strong institutionalizing force for these behaviors, and the program has a very strong F-18 culture. Currently, the Super Hornet and its derivatives (like the EA-18G) are the only F-18 programs. Any legacy culture from previous F/A-18 programs has been nearly erased, and the way the Super Hornet program operates has become known as "the F-18 way." Rightly so, anyone involved with the program has a lot of pride in the aircraft as well as the way they do business.

SilenEyes™ (1999-2004)
Raytheon iFUZION, Tucson, AZ

The SilentEyes™ program was a concept demonstration program run out of Raytheon's iFUZION group. SilentEyes is an expendable, folding, micro unmanned aerial vehicle (UAV).

This small vehicle weighs less than 25 pounds and is roughly the size of a shoebox (Flight International, July 27, 2004). It can be launched from a pylon on the underbody of a larger aircraft; tests of the system were conducted with a MQ-9 Predator B UAV. SilentEyes's mission is low-level, close-range reconnaissance via image capture (camera) and data processing capabilities. The capability of "confirmation identification for both stationary and moving targets," reduces the time to find, target, engage, and assess targets in battle (Raytheon, August 3, 2004). It also has the advantage of being able to access areas where manned access is not possible.

Program History

The program started in the mid-90s at Raytheon with an attempt just to get a vehicle that would fly. Three engineers worked on the design of the expendable, micro-UAV. In 1999, the Air Force awarded Raytheon a small contract to demonstrate the technology at joint services exercises. This contract was awarded in April 1999 and the system was demonstrated in August of that same year. Following this initial demonstration, the Air Force placed additional requirements on the system, such as digital electronics, and another vehicle design was demonstrated in 2000. Shortly after this, money for the project ran out and the system was put on a shelf.

The small group of engineers continued to tinker with the design. In 2002 an attempt to sell the system, the lead of this group used his connections in the company (*"Raytheon is a large company, and I knew someone who knew someone."*) to get a spot briefing the Secretary of the Air Force. At this point, the team had a design that was *"a viewgraph deep"*, meaning the concept worked according to the calculations on paper. The designers had estimated the weight to be 10 pounds, the unit cost to be $15k, and they had created a prototype of the system. During this briefing with the Air Force Chief of Staff, Air Force Secretary, and several Generals, the lead engineer passed around the model and explained the system's capabilities. He was originally supposed to have 15 minutes on the agenda, but based on interest in the concept ended up taking significantly more time. The model provided something tangible that people could relate to, and the Air Force Secretary became very interested in the system. In 2003, the Air Force awarded Raytheon a $3.5 million contract to develop and test the technology (Flight International, July 27, 2004).

The contract and money arrived September of 2003, beginning the development of SilentEyes. Once the team had a contract to work to, they also had a set of capabilities to design to. The system was to be integrated and tested with the un-fielded Predator B UAV in June 2004. The nine-month development period, started with a kick-off session for three days that included several additional people from Raytheon, some suppliers, and the Air Force customer. Although there were 25-30 people at the kick-off, the team still did not include all the key players in the program. During the initial session, the team brainstormed how to accomplish the goals given the capabilities. When they identified expertise that they were missing, they used their contacts and networks throughout the organization to bring people into the team.

During the first part of the development period, the team worked with models to do some wind tunnel testing and some test drops, but they were really waiting for hardware. Much of the hardware procured from suppliers had a six-month lead-time before it would be delivered. This crammed the last three months of the program with all of the build and integration work. There was a limited amount of work that could be done ahead of this, and every time new material arrived, as much work as possible was done with what the team had at that point. For the first three months of the program, the team was rather discouraged. They didn't believe that they could accomplish their goals; they thought the technical challenges were too big. During this period, the team required lots of coaching and support.

Four months into the program the winter holiday break came. After the holiday break, the Program Manager brought in the Company Chief Engineer for the site. He reviewed the program and gave encouragement to the team; this *"put some wind under their sails."* Actual flight hardware started to arrive around this same time. All of a sudden there was a switch and the team got energized; they started to believe they could be successful. According to the Program Manager, *"the last three months of the program were really fun!"*

The system was demonstrated at Edwards Air Force Base (AFB), launched from a pylon-mounted canister on a Predator B UAV, in May and June 2004 (Raytheon, August 3, 2004). These tests were successful, but due to a number of factors, money for the SilentEyes program ran out a second time. Since June 2004, no further development work has been done, but Raytheon continues to market the concept. According to the Program Manager, *"we lost traction, and the team dispersed, but with a couple of phone calls, they'd all come running back."*

Program Execution

During the development and testing phase, there were about 20 people on the team. This is a small number for a typical aerospace program, but it is not unusual for a research and development (R&D) effort. Everyone was involved in all aspects of the program. Although the team was not formally collocated, they took over a conference room that was the integration and test lab, the team's meeting space, and the location where all the program information was posted on the walls. This central location provided a focal point for the team. It was from this conference room that weekly teleconferences were held with suppliers to keep them integrated into the program. Whenever a question would come up, all the relevant information and people were right there in the same room.

Because the team did not have time to fully simulate all of the concepts, they used prototypes extensively. They would design something, prototype it, then build it. Prototypes were also used a means of communication for the team. They would make several copies of a prototype and send them to their suppliers and customers so everyone would have a common point of reference. The customer used these prototypes to fine-tune some of specified key characteristics of the system. The prototypes made the desired capabilities real; this allowed discussions of issues to be focused on something tangible. Prototypes also created a connection between product and process, how the system would be built and operated.

Another key to program execution was all the work the Program Manager and the Deputy Program Manager did to buffer the team from the programmatic details. The team could focus on accomplishing their goals without being hampered by the details of doing business. For example, the Deputy Program Manager took care of expense reports for the team so they didn't have to worry about them. There was a mind-set with the program managers that the entire team did not need to worry about costs, that's what the managers get paid for. The team used Integrated Master Plans and Integrated Master Schedules (IMP/IMS) to keep the team on schedule. The team never missed a schedule milestone. Some of the milestones moved for other reasons, and the team often needed the extra time, but they were never the reason why a milestone slipped.

Additionally, outside resources were used to motivate the team and ensure success. Peer reviews, using Subject Matter Experts (SMEs) from other parts of the company, were conducted. The team did not have money to bring in specialists to work on the team, so they would provide the team with some training, and then bring in a specialist for a review. The Program Managers continually focused on enabling the team to execute and succeed. They created a set of rules about how the team worked and how the parent functional organizations worked. In this sort of matrix organization where people are accountable to a functional organization as well as a program, people are often hindered by the fear of getting beaten up from one side or the other. The Program Managers acknowledged this and did what they could to break down these barriers. They also realized that you couldn't bring the conventional management techniques and style that are used on 10-year aerospace development programs to a nine-month project. They started with a different mindset about how to manage the program. According to the Program Manager, *"we worked hard to build the team, knock down barriers, and respect the individuals on the team."*

The SilentEyes program was not without its challenges though. The tests were conducted on an un-fielded system, the Predator B. Predator B was being developed by General Atomics Aeronautical Systems, Inc. concurrently to the SilentEyes program. Although General Atomics was supportive of the integration and testing of SilentEyes, it was not their priority. In fact, development and fielding of Predator B has taken priority for the Air Force as well. This has contributed to the difficulty in selling the SilentEyes concept. It has required a significant shift in funding priorities to move the fielding of Predator B forward.

Another challenge in working with General Atomics is that they are a relatively new company in the aerospace industry. They are not one of the veteran companies like Raytheon or Boeing. They are still adapting and their aircraft is not mature. Additionally they have faced pressures to produce more of their systems, both the A and the B versions in order to meet desired capabilities in the field. Raytheon helped General Atomics figure out how to integrate the SilentEyes system with the Predator vehicle. Both organizations shared some pain in integrating and testing the systems, but this helped with the team building.

The compressed timeline and limited financial resources also presented numerous challenges. The team did not have time to operate in the way most people were used to, nor did they have funding to bring in experts whenever they got stuck. For example, people were skeptical of the schedule, assuming that some margin had been built in. They often asked, *"When do you really need it?"* The schedule pressure also forced the team to make some concessions at the end of the program. In order to deliver on time, the team did not spend time perfecting the design and the product they ended up with worked, but was not an ideal, or even a producible design. In the end, the team rallied around the goal they shared, and they did what they had to in order to be successful.

X-35 JSF Proposal (1996-2001)
Lockheed Martin Aeronautics, Fort Worth, TX

Two companies competed to develop "what could be the military's last manned fighter jet" (Breen, 2002, p. 66). The Joint Strike Fighter (JSF) aircraft competition pitted rivals Boeing and Lockheed Martin against each other in what was arguably the biggest fighter competition ever. "The ambitious idea behind the JSF is to address several chronic problems of the U.S. military acquisition policy simultaneously" (Fallows, 2002, p. 63). The idea is simple; achieve economies of scale by having a family of similar aircraft designs to fill the needs of the Air Force, the Navy, and the Marines. This means a more affordable aircraft for the customer, larger production lots and larger runs for the producers and suppliers, and interoperability for the warfighters.

Commonality across the services is difficult to achieve though, since the different customers have different missions and have typically had vastly different requirements. In order to meet the needs of the various services, the competition required each team to design and demonstrate three variants of aircraft: a Conventional Take-Off and Landing (CTOL) variant for the U.S. Air Force, a Carrier Variant (CV) for the U.S. Navy, and a Short Take-Off, Vertical Landing (STOVL) version for the U.S. Marines and the U.K. Royal Air Force and Royal Navy. Before the request for proposal (RFP) for the JSF competition was released, the U.S. signed an MOU (Memorandum of Understanding) with the U.K. to participate in the Weapons System Concept Demonstration (WSCD) phase (Jane's Information Group, 2005g).

Lockheed Martin positioned themselves with Northrop Grumman, and BAE Systems as teammates to develop and demonstrate the X-35 variants. With a team of roughly 500 people, after nearly 4 years, the Lockheed Martin team was selected to develop and produce the JSF, or

F-35 as it has been renamed. This competition was a unique combination of technical and managerial challenges. The JSF competition is fascinating because of the magnitude of the task: develop and demonstrate one design with enough flexibility to meet three different sets of requirements AND ensure affordability and lifecycle value of the system so that the services can afford to buy as many of the aircraft as they need to in order to replace their aging fleets. While admirable, these results are unprecedented. Not only have they not been achieved before, attempts at joint aircraft in the past have ranged from unsatisfying to disastrous results (Fallows, 2002). When it comes down to it, in the defense aerospace industry, technical challenges are often overshadowed by the inability to manage costs. Escalating costs create long-term vulnerability for the military when they cannot afford to buy systems in the numbers they need them in. The effect is nearly as crippling as systems that do not meet the technical requirements. It is an interesting trade-off between technical superiority and affordability. The JSF is one of the most well known programs to explicitly focus on affordability as an important and explicit system requirement.

Given the extreme challenge, the results of the JSF competition were impressive. Up through the point when the Lockheed Martin was announced as the winner, costs of both rival models were "surprisingly close" to target levels (Fallows, 2002). The Lockheed Martin flight demonstrations also included two unparalleled "Mission X" flights: short take-off, supersonic dash, and vertical landing. Wow! It was well known when the competition ended that the biggest challenge lay ahead, in actually executing plans, keeping the costs down, not sacrificing technical excellence, and meeting commitments to deliver an affordable F-35. Although the end of SDD has yet to be seen, the program has run into some trouble, slipping schedule, overrunning cost, and having weight problems on the aircraft (one of the most difficult technical requirements to manage in an aircraft development). "If the cost of this airplane rises even half as much as the historical norm, the JSF will not come close to its advertised purpose of replacing today's aging fleet"

(Fallows, 2002, p. 65). The Lockheed Martin team proved their ability to perform on the X-35, and now, the hope is that they can rise to meet the challenge again on the F-35.

Program History

The JSF program began as two different R&D efforts that were merged, forming the requirements for the Joint Advanced Strike Technology (JAST) effort in 1994. In 1995, the program was renamed JSF. The final RFP for WSCD, the final stage of the JSF competition, went out June 1996. McDonnell Douglas, Boeing, and Lockheed Martin each submitted a proposal. November 16, 1996, two companies were selected to develop prototypes of the JSF, Boeing and Lockheed Martin. Boeing would develop the X-32 and Lockheed Martin the X-35.

Shortly following this announcement, in December of 1996, McDonnell Douglas merged with Boeing, creating a big threat to Lockheed Martin in the JSF competition. Lockheed Martin suddenly looked like the underdog. In response, Lockheed pursued teaming with Northrop Grumman and BAE Systems. Although partnership in aircraft development is not unheard of, Lockheed Martin, Northrop Grumman, and BAE Systems have traditionally been more fierce competitors than partners. But in this case each company could contribute complementary strengths to the team, and it was realized that they needed to combine their efforts to be able to compete with the new Boeing. Lockheed Martin offered Northrop and BAE their only chance to be part of the JSF program, Northrop Grumman brought significant experience with stealth technology and the Navy customer, and BAE offered expertise in STOVL technology as well as having advantageous U.K. ties (Breen, 2002). In August of 1997, the leadership of the teammates met to lay on the table what each could contribute and how they would work together.

Two aircraft were produced as part of the competition. Assembly of the first X-35 began in April of 1998. The first flight of the X-35A (CTOL variant) occurred two and a half years later, October

24, 2000. The X-35A was converted to the X-35B for STOVL demonstration by adding the lift fan system. The second aircraft produced was the carrier variant, the X-35C. On June 23, 2001 the first vertical take-off and landing was achieved, and a day later, the first sustained hover occurred (Jane's Information Group, 2005g). Just a couple of weeks later, the first airborne transition from STOVL to conventional aircraft occurred on July 9. Two Mission X flights occurred on July 20 and 26. The fast paced flight testing concluded August 6, 2001 (Jane's Information Group, 2005g).

The competition came to conclusion after the final proposals were submitted and the winner was announced on October 26, 2001. Lockheed Martin was awarded a $19 billion contract for the SDD phase, including 14 flying aircraft and eight non-flying aircraft for testing. The 14 aircraft breaks out into five CTOL, five CV, and four STOVL aircraft. At the time, the SDD phase was planned to last 126 months.

Program Execution

There are many important factors that led the Lockheed Martin team to win the JSF competition. "The Battle of the X-Planes," as PBS called it in their documentary (Jorgensen, 2003), was a very high profile program. It represents an enormous defense contract, in the ranges of hundreds of billions of dollars for thousands of aircraft over the next two decades. It also represents a milestone in aviation history as the development of what is likely the last manned fighter aircraft. As a winner-take-all decision, the end of the competition was history in the making, dictating the role both the winning and losing companies would play in the timeline of aviation history. The competition has been publicly documented extensively, but there are a few key aspects worth highlighting here.

One of the first critical moves Lockheed Martin made was to bring Northrop Grumman and BAE Systems on board as teammates. As articulated earlier, each organization brought unique expertise and connections to the team. The real novelty in this teaming arrangement is not simply that the three companies joined together, but rather that they created a true partnership instead of the traditional prime-sub contractor relationships that permeate most aerospace "partnerships." "Typically these projects consist of a prime contractor that doles out parts of the jet's development to dozens of subcontractors and hundreds of smaller suppliers. But such arrangements encourage predictable behavior: The prime browbeats the subs, and the subs overcharge the prime, resulting in delays and cost overruns" (Breen, 2002, pp. 73-74). With the intense focus on affordability, in fact by having cost explicitly in the in the requirements document, the predictable results of the prime-sub relationships could not be tolerated. Everyone in the program realized they had to do business differently if they wanted to win the competition, but this did not make it any easier. In the past, every organization had bad experiences with teaming. Lockheed Martin took the lead in offering a new approach to teaming, one that had been talked about but rarely put into practice in the past. When Lockheed approached Northrop and BAE it was with an offer for a real stake in the program, 30 percent combined, as strategic partners (Breen, 2002). Additionally, the program adopted a "best athlete" strategy. Regardless of which organization individuals worked for, if they were the best suited to lead a particular area, they would have the job. This resulted in an organizational structure that crisscrossed organizations, with Lockheed employees working for Northrop Grumman managers, BAE employees working directly under Lockheed Martin managers, and so forth. This was a real team environment.

Decisions about how to divide work up were contentious enough in the traditional mode of operating. Finding and utilizing expertise from across three different companies was another matter all together. Lockheed Martin brought in a retired Marine Corp general to help with the process. Harry Blot was the catalyst for a summit held in Aspen in July 1997, which brought together the leadership of the three organizations. The question he posed was, "We have different norms, different behaviors, maybe even different goals. So how do we work together" (Breen, 2002, p. 74)? Blot took on the challenge of not only posing the question, but also getting the leadership past their preconceived expectations and engaged in solving the teaming problem. According to Martin Taylor, the BAE program manager at the time, "At any point, it would have been easier to say, 'This is too difficult. Let's go back to the old way and split the plane up.' But the management team made it clear that that was an unacceptable answer. And they were right" (Breen, 2002, p. 74).

The teaming challenges were not limited to the partnership between the three contractors. Before Northrop Grumman and BAE were brought on board, Lockheed Martin struggled with teaming relationships internally between their Skunkworks division in Palmdale, CA and their division in Fort Worth, TX. Lockheed Martin acquired the Fort Worth division from General Dynamics in 1993. Shortly following this, when the initial requirements for the JSF were released and companies were forming their strategies, there was an internal debate over which division should led the JSF effort. Palmdale and Fort Worth were fighting with each other in front of officials from the Pentagon, and it reflected poorly on Lockheed's ability to compete. In the second phase of the competition, the Pentagon awarded $20 million to the McDonnell Douglas and Boeing teams but only $10 million to the Lockheed team (Breen, 2002). This was enough of a wakeup call that Lockheed leadership wrote a formal agreement indicating that the Palmdale division would lead the prototype development, but Fort Worth would lead the program. The cultural divide between the R&D environment at Palmdale and the production program environment at Fort Worth still existed, to say nothing of the differences with the division in Marietta, GA. These internal cultural issues between these three divisions remained a challenge for Lockheed Martin leadership.

In the defense industry, the military services historically do not work together any better than the contractors do. On the customer side of the program, joint programs are generally led by an executive service, and the program takes on a flavor of that institution with the other participating services fading into the background. To solve the inter-service rivalry, a rotating command structure was established, switching every two years between an Air Force general, a Marine general, and a Navy admiral. Every two years may seem frequent for a major change of leadership, but it is not unusual for military leadership in any position. To keep the balance between the services, in addition to the rotation, the military program manager reports to a civilian from the other service. When an Air Force general is running the program, they answer to the assistant secretary of the Navy, and when the Navy or Marines are running the program, they answer to the assistant secretary of the Air Force.

In addition to creating the formal teaming structure and negotiating working relationships, several enabling systems and behaviors had to be established. Since authority, leadership, and responsibility were not limited by organizational boundaries, information could not be either. Common information sharing tools and common processes had to be established to span the entire program, enabling real-time access to shared information. Master and mirror databases were established for design and programmatic information, but more important than the technology, the underlying standards and processes for collecting and sharing information had to be constructed. Along the lines of the "best athlete" philosophy for individual leaders, best practices from the various organizations were identified and shared. For example, the program uses an Earned Value Management System (EVMS) to track adherence to cost and schedule targets. The Northrop Grumman EVMS system was more advanced than the Lockheed Martin or the BAE systems, so the entire program adopted it.

Lastly, in order to promote and maintain integration across the program, a common vision with a set of guiding principles was established. The days where the individual organizations had different goals could not last for long, so the JSF Effectiveness Team (JET) was created. This team included Lockheed Martin, Northrop Grumman, BAE, and the customer. They identified a set of guiding principles that remain with the program today. Every Friday morning during the weekly program review, presenters had to relate what they were talking about to the guiding principles. It started as a motivational tool but it became common practice as the team internalized these principles. Now several years later, the guiding principles have become institutionalized as the way the JSF program operates. Although the team has grown from 500 people during the competition to nearly 5000 people at the height of development, a core group of original participants are still involved in the program. This has created a corporate memory of the how the program operated during the competition, and has helped institutionalize the guiding principles of the program into commonly held assumptions.

Electronics

F-16 Radar (1995-present)
Northrop Grumman Electronic Systems Sector, Baltimore, MD

The F-16 fire control radar began with the AN/APG-66 designation. The AN/APG-68(V) series was derived from the APG-66 model, and it was first incorporated on F-16 Block 30/40 aircraft. The radar are delivered to Lockheed Martin for integration with the aircraft, and then delivered to one of 24 countries that buy the planes. Combined, there have been more than 6,500 copies of the APG-66 and APG-68(V) radars produced by Northrop Grumman (Jane's Information Group, 2005a). The radar is a modular system of six Line-Replaceable Units (LRUs), the antenna, transmitter, low-power radio frequency (RF) unit, digital signal processor, computer, and control panel. Each LRU has its own power supply and the modularity allows for very short replacement times with no special tools or equipment (Avitop, 2005).

Program History

The F-16 has been in production since 1976, currently more than 4,000 aircraft have been delivered to 24 countries. Northrop Grumman Electronic Systems Sector (originally Westinghouse) has been supplying the radar system since the first aircraft was produced

(Northrop Grumman, 2005). The original system (APG-66) was included until Block 30 aircraft were delivered in 1985. The APG-68 radar began with the (V)1 through (V)4 variants that were included in Block 30 and Block 40 aircraft. The (V)5 was first installed on Block 50 aircraft for the U.S. Air Force. (V)7 and (V)8 were first delivered on export aircraft and the current (V)9 is included on the Block 50/52+ aircraft (Jane's Information Group, 2005a). The (V)9 upgrade to the radar was more significant than previous modifications (Northrop Grumman, 2005). The (V)9 radar is the newest system in the U.S. F-16 inventory. As an aside, the most recent development of the F-16E/F (Block 60) aircraft, for United Arab Emirates, includes a new active, electronically scanned array (AESA) radar system.

The evolution of the F-16 radar system has improved aircraft performance in both air-to-air and air-to-ground operations (Northrop Grumman, 2005). Production of the (V)9 radar is on-going, to meet production needs of the aircraft, which is expected beyond 2010. Northrop Grumman also produces an upgrade retrofit kit that brings earlier APG-68 radars up to the (V)9 capability and standard. This upgrade is available for aircraft from Block 20 through Block 50 (Northrop Grumman, 2005). Additionally, Northrop Grumman is four years into a 23-year engineering services technical support contract for spares, repairs, and systems modifications for APG-66 and APG-68 radars in service worldwide (Jane's Information Group, 2005a).

Program Execution

The role of the program manager is emphasized in the F-16 radar programs. There are different programs for the development and production of different variants, but a common thread through these programs is a focus on the program manger's roles: first, in personally establishing and maintaining a good relationship with the customer, second, acting as a liaison between the customer and company, and third developing people on the program through mentoring and enabling them to execute their jobs. Program managers working on the F-16 radars make personal commitments to work closely with their customers. This stems from the

Vice President for F-16 programs, as he leads by example, making the commitment to put the customer first. This is accomplished through an intensity and variety of interaction with the customer. It is not unusual for a program manager to have two to three contacts with a customer representative every day. In addition to fostering good customer relations, the program managers act as a liaison for their company when dealing with the customer, and they act as liaisons for the customer when dealing internally with their company. Program managers often see their role as an advocate for their company when dealing with the customer, but advocating the customer position internally can be easily overlooked. On the F-16 radar programs, this advocate/liaison role is explicit. The third program manger role is to develop people under you on the program. Northrop Grumman has many programs at the Electronic Systems Sector, so there is plenty of opportunity to develop hands-on expertise in program management. The program managers throughout the organization make mentoring upcoming talent part of their duties. This not only helps develop individuals, but it places program managers in an enabling role with regard to program execution. Focused on mentoring, program managers are oriented towards enabling others to do their jobs.

In addition to the role of the program manager, planning and measuring is an important part of the F-16 radar programs. While reporting systems are good for sharing information, they are not good for managing. Good plans and measures that reflect the health of the program are required for managing execution. Item by item reviews are used to provide attention to detail. These are reviewed on a daily, or sometimes more than once daily, basis to provide the detailed information needed. It is important to strike a balance between a high-level and detail-oriented focus. Good plans and metrics provide accountability for what gets accomplished.

F/A-22 Radar (1991-present)
Northrop Grumman Electronic Systems Sector, Baltimore, MD

AN/APG-77 designates the radar system for the F/A-22 weapon system. The radar is a central part of the integrated avionics suite. The integration of the radar, the electronic warfare suite, and the communication and navigation subsystems is new for combat aircraft. The integrated avionics system is one of four main attributes that provide the F/A-22 tactical advantage (the others are stealth, maneuverability, and supercruise, or the ability to fly faster than the speed of sound without afterburners). The radar system is made up of an active, electronically scanned array (AESA) antenna. This array is made up of more than 1,000 small transmitter/receiver modules. Individually, the modules output small amounts of power, but together they provide substantial capability. Development of the AESA component for the F/A-22 radar has benefited both the F-35 and F-16E/F aircraft, each of which also incorporates this technology. The AN/APG-77 radar can obtain electronics intelligence, jam enemy electronics systems, provide surveillance, and perform secure voice and data link communications simultaneously (Goebel, 2005). The F/A-22 radar is a joint venture between Northrop Grumman Electronic Systems Sector and Raytheon Integrated Defense Systems. Boeing is responsible for integrating the radar with the rest of the avionics system, and as such, they act as the customer for the radar system. Lockheed Martin integrates the avionics suite with the airframe and delivers the weapons system to the U.S. Air Force.

Program History

After more than 10 years in development, the first radar hardware was delivered to Boeing's Avionics Integration Laboratory in 1998 (Jane's Information Group, 2005b). The first flight of the AESA radar was on F/A-22 Raptor 4004 in late 2000. Full radar functionality was demonstrated with Raptor 4005 when the hardware and software were combined. Between 1999 and 2000, the radar system was extensively tested on Boeing's 757 Flying Test Bed before it was integrated with the F/A-22 airframe. Low Rate Initial Production (LRIP) began in 2001 after all

11 Engineering and Manufacturing Development (EMD) phase radar systems were delivered. These EMD systems were all delivered on time and within cost projections (Northrop Grumman, January 5, 2001).

Currently, the F/A-22 radar program has three major components, a production effort for the third generation system, a development effort for a fourth generation system to incorporate the air-to-ground capability, and a modernization effort. The fourth generation system is transitioning into production as the third generation system phases out.

Program Execution

This program started as a joint venture between Westinghouse (now Northrop Grumman) and Texas Instruments (now Raytheon). These two organizations had good working relationships that have survived and still largely exist today. The partnership was initiated because Texas Instruments had the capability to produce a high volume of the modules Westinghouse needed to build the AESA. It was established as a 60/40 partnership with Westinghouse having the larger share. Now, with the fourth generation development, Northrop Grumman has the sole design authority for the system. Even though the company names have changed, it's largely the same individuals on the programs from both sides, and the relationship between the organizations remains good. There is an acknowledged co-dependency between the organizations; they need each other in order to profit from available contracts.

Another important aspect of this radar program is use of informal social networks to find information. Northrop Grumman has around 8,000 people at the Baltimore facility working on approximately 300 programs. Functional organizations (e.g. engineering) "own" the human resources that are allocated to various programs. The programs themselves have few direct reports. Because the formal program organization is relatively small, people often have to rely on their informal connections to find and gather information. As one person articulated, *"it's mostly who you know from where you've been, these networks are critical."*

AN/APG-77 stays integrated across the various development and production efforts, and across organizations by having detailed reviews. At Northrop Grumman, these reviews are called "page and line" reviews because they literally cover numerous pages of items, line by line. There are also weekly program management meetings to focus on the hot topic for the week. These meetings, as well as others, provide a venue for people dedicated to the program to bring in new information they have collected through their individual networks.

Joint Tactical Radio System (JTRS) (2002-present) Rockwell Collins, Cedar Rapids, IA

JTRS (pronounced "jitters") is the Joint Tactical Radio System, a Department of Defense (DoD)-wide effort to provide seamless multi-channel voice, data, imagery, and video communications with interoperable capabilities to the U.S. military services and their allies (JTRS Program Office, 2005a). This will enable real-time information sharing in the joint battlespace, something that is not possible today with the current systems specialized for particular service or mission requirements. The information superiority that will be provided by JTRS is an important part of the DoD transformation program Joint Vision 2020 (JTRS Program Office, 2005a). Because the JTRS scope is so large, and in order to bring the user requirements closer to the developers, JTRS development and production is divided into smaller programs. There are four programs within JTRS, three of which will be discussed here.[6] The Ground Mobile Radio (GMR) program, known as Cluster 1 until January 2006, is developing a software programmable and hardware configurable digital radio networking system primarily for U.S.

[6] Cluster 2 is a program for the Special Operations Forces (SOF) to upgrade an existing handheld radio to compliance with the Software Communications Architecture (SCA) which the other JTRS developments are based on.

Army ground vehicular and aviation rotary wing requirements. One of the primary notions behind JTRS is to separate the software and hardware requirements in the system. JTRS is designed so that changing the software can change functionality of simple hardware, and so that hardware can be upgraded without requiring modification to the software (JTRS Program Office, 2005b). The Handheld, Manpack, and Small form fit (HMS) program, formerly known as Cluster 5, is developing the system into portable manpacks, handheld radios, and other small form fit applications for the U.S. Army and Special Operations Forces (SOF). The Airborne, Maritime, and Fixed (AMF) program (a combination of former Clusters 3 and 4) is focusing on integrating the system with existing and new assets for the U.S. Navy and Air Force. In addition to being divided into these sub-programs, JTRS follows an evolutionary acquisition strategy, the system will be developed and fielded in an evolutionary manner, providing increasing capabilities as technology development and funding allows (JTRS Program Office, 2005b).

Each program on its own is a significant effort, but they are inherently interrelated. For example, GMR includes the main software development effort. HMS and AMF both rely on the technology development of GMR. To provide some perspective of relative scopes, HMS has a broad range of applications, spanning from sensors, to unmanned vehicles, to munitions, to handheld radios, to manpacks. AMF has a large integration challenge with over 150 different platform types. Each program is managed separately, but there are several companies involved in more than one JTRS program. Obviously, these companies attempt to leverage synergies between their efforts. One such company is Rockwell Collins. As a subcontractor on these programs, Rockwell Collins is responsible for developing much of the waveform and hardware technology in the system. Their contributions are central to the functionality of JTRS. The combined effort across these programs provides Rockwell Collins significant potential for commercial applications based on the underlying technology. This is a specific example of how companies involved in more than one JTRS program can leverage their involvement.

Program History

The concept for JTRS began in early 1997 as the Programmable, Modular Communication System (PMCS). After a couple of contracts for technology demonstration, this became the JTRS family of programs. Cluster 1 (GMR) was the first JTRS programs initiated in June 2002 when a 6-year contract was awarded to Boeing to begin the System Design and Development (SDD) phase of the program. The program was on track for the first year and a half when early operational testing had to be rescheduled by 6 months (GlobalSecurity.org, 2005b). This was due largely to new requirements and increasing scope. Low Rate Initial Production (LRIP) was anticipated to begin at the end of 2005, ending with a full and open competition for full rate hardware production. Production units of the GMR program will not be available until 2010 (Schiavone, May 3, 2006).

In the meantime, the proposal for Cluster 5 (HMS) was submitted in October of 2003, and the SDD program was awarded to General Dynamics in July of 2004. SDD for HMS is estimated to be complete in 2007. After Cluster 3 and 4 were combined in late 2003, the AMF program began a pre-SDD phase that will span a total of 21 months when it is complete (planned 15 months plus a 6 month extension). The SDD award was expected in June 2006. Production for the AMF program is expected to begin in 2010 and last for nearly a decade. These individual programs each have their own schedule for proposal, contract award, SDD, and production, but the schedules overlap considerably and the interdependencies between the programs are critical to the overall JTRS success. The total production for JTRS is estimated around 180,000 radios for the U.S. military customers alone. To manage some of these interdependencies, a Joint Program Executive Office (JPEO) was formed in spring 2005. This office is charged with coordination between the cluster programs.

Program Execution

In general, the various JTRS programs are using the restructuring of the government customer into the JPEO as a catalyst to work towards more collaborative relationships in the programs. These programs are important for the companies involved. They represent significant amounts of business as well as future opportunity for all the stakeholders. Even though the JTRS concept and program history can be outlined coherently as a single effort, the programs have truly separate program management efforts, each with their own individual characteristics, challenges, and approaches. The following sections outline key execution issues for each of the programs studied.

GMR Execution

Boeing, BAE, Rockwell Collins, and Northrop Grumman are part of the GMR program. Boeing is the system integrator; BAE and Rockwell Collins are developing technology and providing the hardware and software. After the SDD phase, BAE and Rockwell Collins will compete for the full rate production contract. This redundant capability is in place so the government customer avoids having a sole source for the systems. BAE and Rockwell must work together during the first part of the program to design the system, knowing only one of them will eventually produce the system. BAE and Rockwell have solid working relationships that go back nearly 20 years. The two organizations have a history of working together towards a common goal, even though there has been some disagreement as to how the work should be divided on the GMR program. On the other hand, the relationship between Boeing, as the system integrator, and Rockwell or BAE is more of a traditional, arms-length, supplier-contractor relationship. In this situation, the prime contractor often makes decisions autonomously then flows down implications to their subcontractors. This arrangement typically creates time lags and information disconnects in programs. This has been the case on the GMR program where there has been a lack of focus on integration issues from the prime level down throughout the program. Additionally, this arms-length relationship separates the developers from the customers by having the integrator act as a filter and a go-between. This limits the interaction between the people who specify the requirements and the people who implement them. An example of the communication barriers that can be established, it took between seven and nine months to negotiate the work share arrangements between the team once the contract was awarded. During these early months, the program was essentially stalled while the organizations fought over how work will be divided between them. Once work had been assigned and this was behind them, the GMR program has used standard reporting mechanisms to track their progress effectively. Although the GMR program hasn't gone perfectly, it is paving the way for the HMS and AMF programs. The subsequent efforts are able to implement lessons learned from the GMR experience.

HMS Execution

The prime contractor on the HMS program is General Dynamics. Rockwell Collins, BAE Systems, and Thales Communications are other major players in the program. The HMS team works together differently than the GMR team does because of the different organizations and individuals involved. The HMS team is focused on execution, enabling the whole program to stay on track. All along there has been time invested in building relationships between the teammates. The subcontractors each have offices at the General Dynamics facility. This has helped develop trust and communication on the program. As a result there are informal communication channels between the customer and the subcontractors about technical topics, "because it's the right thing to do." This is in sharp contrast to the way the GMR program operates. These relationships have developed differently from those on the GMR program, largely because they are newer. In the GMR program, Boeing, Rockwell Collins, and BAE all have long histories together, with patterns of interacting well established. In the HMS program, Rockwell and BAE have a history together, but the relationships with General Dynamics are fresh and are based on the most recent interactions.

AMF Execution

Several factors have combined to influence the way the AMF program is executed. First, there is experience with the organizational relationships in the GMR and HMS programs. Second, the extended pre-SDD phase has lengthened the competitive period (there is more than one team vying for the SDD contract), motivating all involved to do whatever possible to win the SDD contract. In combination, these factors have motivated the AMF program to differentiate itself. Boeing and Lockheed Martin lead the two teams competing for the SDD contract. Only the Boeing team was studied. The Boeing-led program includes a core group of Boeing, L3 Communications, Rockwell Collins, Northrop Grumman, BBN Technologies, and Harris Communications. There is no assigned prime contractor in this core group, although Boeing has taken the lead. Even before any contract was awarded for the pre-SDD phase, the organizations pooled their resources, looked at core competencies, and divided up the work between the team members. This up front work share agreement eliminated any negotiations after the contract was awarded. The program team could start working productively on day one after the contract was awarded. This upfront investment also created a strong sense of a shared destiny between the organizations. The AMF program execution sits in strong contrast to the GMR program. Where the GMR program has strained relationships between organizations, the AMF program truly has teammates working together. The GMR program lost considerable time after contract award negotiating work share; AMF established this much earlier in the program, saving time during the contract for productive work and developing a shared vision for the program at the same time.

The relationships on the AMF program have developed productively, even under fairly interesting circumstances. If the Boeing-led team wins the SDD contract, Harris and Rockwell Collins would eventually compete for the production contract (similar to the competition between Rockwell Collins and BAE for GMR and HMS). Both Harris and Rockwell Collins have to be willing to give up market share they currently have in order to participate in the program. If Harris were to win the production contract, they would take most, if not all, of Rockwell Collins military aircraft business, which is not an area Harris is a big player in right now. On the other hand, if Rockwell Collins were to win the production contract, they would take most, if not all, of Harris's maritime business, which Rockwell is not currently involved with. In either case, the significance of this program and the competitions are not lost on the organizations, but they have all chosen to work together to maximize their chances of even getting to compete for the production contract (they have to win the SDD contract first).

Munitions

Case A (1997-present)
Raytheon Missile Systems, Tucson, AZ

Identification and summary of this case are not available at the time of publishing.

Exoatmospheric Kill Vehicle (EKV) (1998-present)
Raytheon Missile Systems, Tucson, AZ

The Exoatmospheric Kill Vehicle (EKV) is a critical part of the Ground-based Midcourse Defense (GMD) system. EKV is something between a missile and a satellite that integrates with the Ground-Based Interceptor (GBI), the weapon component of GMD. Additionally, the GBI is the long-range interceptor in the "layered" (in terms of range and flight interception) Ballistic Missile Defense System (BMDS) run by the Missile Defense Agency (MDA) in the Department of Defense (DoD). EKV is the payload of the GBI booster vehicle, and it is the portion of the system responsible for destroying ballistic missiles carrying weapons of mass destruction (nuclear, biological, or chemical) headed towards the U.S. The EKV achieves this by colliding with the incoming weapon, "completely pulverizing it" (Raytheon, 2005a). Although the EKV itself is relatively small (55 inches long and 24 inches in diameter, weighing roughly 140 pounds), the closing velocity of the EKV on a target is around four miles per second, or 15,000 miles per hour.

The force of this impact, aimed precisely at the incoming missile's payload is sufficient to destroy both the target and the EKV. The EKV is a complex system with a multiple-waveband infrared (IR) seeker at the heart. The IR seeker is made up of two infrared sensors and one visual sensor attached to an optical telescope, a cryogenic cooling system, and the supporting hardware and software. The EKV also has its own propulsion, communication link, discrimination algorithms, guidance and control system, and computers to support target identification and intercept decisions even after it separates from the GBI. The EKV is designed to withstand the rigors of the in-flight environment en route to performing its mission of locating and destroying its target using kinetic energy, or "hit-to-kill" technology. The EKV is produced by Raytheon Missile Systems for Boeing as the Lead Systems Integrator (LSI) or Prime Contractor of GMD.

Program History

Ballistic missile defense has been on the horizon since the late 1950s, but its current path of development began in March of 1983 when President Reagan announced his Strategic Defense Initiative, nicknamed "Star Wars" by critics. Although scaled back from the original conception, ground-based missile defense has remained active. Competition to build the EKV was launched in 1990 and originally managed by the Army. In 1995, the competitors were down selected, leaving a Boeing team and a Raytheon team. In 1998, the Ballistic Missile Defense Organization (BMDO, now the Missile Defense Agency) awarded a contract to Boeing as the LSI to oversee development of the EKV, the booster rocket, tracking radars, and battle management systems (Graham, 2003). One of Boeing's first tasks was to select either their own team or the Raytheon team for the EKV. Shortly after the LSI award, a competition sensitive software test plan from Raytheon was found in a Boeing conference room. It is unresolved exactly how this document got to Boeing, but it is assumed an Army official inadvertently left it there after a visit (Graham, 2003). The scandal grew when it was realized that Boeing team members kept a copy of the document for analysis even after it had been reported. Boeing took action against several individuals involved, but Raytheon remained unconvinced that the competition could proceed fairly. The Boeing team withdrew from the competition and it was decided that the designs were mature enough that the contract could be awarded to Raytheon. The competition was decided more on a technicality than because of a technical advantage, and the premature end to the competition likely increased the cost of the system (Graham, 2003).

After a rocky start, the program continued development and began testing in 1999. EKV achieved hit to kill successes in five of seven tests between 1999 and 2005. 2002 was the last test success, but the 2004 and 2005 failures were not failures of the EKV itself, but rather of other aspects of the integrated system. These other failures prevented the EKV from being tested in both of these cases. Most recently in December 2005, another test was performed successfully, but using a simulated target.

In parallel with the system testing, there have a sequence of largely political decisions about making the system operational. President Clinton was supposed to make a decision about deployment in the summer of 2000, but eventually deferred to President Bush (Graham, 2003). In 2002, President Bush directed the DoD to begin fielding limited missile defense capabilities by 2004. Raytheon began delivering EKV payloads in November of 2003, and the first GBI (booster and EKV) was lowered into a silo in Fort Greely, Alaska in July 2004. Since then, a total of 12 GBIs have been emplaced, 10 in Alaska, and 2 in Vandenberg Air Force Base, California (Missile Defense Agency, 2005).

Program Execution

As prime contractor, Boeing is responsible for design, development, testing, and integration of the GMD elements into a viable system capable of defending against limited ballistic missile attack. The Raytheon kill vehicle represents a critical component of the GMD program. The

2004 and 2005 test failures and other production issues have brought added scrutiny to the program, inviting a complete design review from within Raytheon, and extra oversight from Boeing. Boeing has several on-site representatives at the Raytheon plant, largely to ensure that EKV production is running smoothly.

The program also has a complex organizational structure. Beyond the traditional matrix organization, EKV has programs within programs focused on developing, producing, and testing the system. There are two programs within the EKV program that provide kill vehicle payloads for the GMD system. Raytheon is currently under contract to provide Test Bed/Capability Enhancement (TB/CE) payloads for use in flight tests and to provide Limited Defensive Capability for the United States against ballistic missiles. In early 2007, Raytheon will begin delivery of Capability Enhancement II (CE II) payloads.

The EKV, as an integral part of the GBI and GMD systems, will be successful, even if it is never used, if it is proven convincingly through testing and as a result deters future development of the weapons it is meant to combat.

Joint Direct Attack Munition (JDAM) (1995-present)
Boeing Integrated Defense Systems, St. Charles, MO

The Joint Direct Attack Munitions or JDAM is a guidance tail kit that is attached to standard bombs to create a smart weapon. JDAM has four current variants in production, two different 2,000 pound weapon configurations (for the general purpose and hard target, "bunker buster" bombs), a 1,000 pound variant, and a 500 pound variant. This family of weapons is produced on a single production line, led by the Boeing Company. The munitions kit includes the tail kit (including the guidance control unit), strakes which fit along the sides of the warhead, and the warhead itself. Over 20,000 weapons have been used in combat, more than 100,000 have been delivered, and production rates peaked at more than 35,000 in 2005 (approximately 3,000 units per month) (Boeing, July 2005). JDAM is currently integrated on nine families of Air

Force, Navy, and international aircraft. In addition to quickly becoming a "weapon of choice" by many airmen after it was fielded, the JDAM program has been widely recognized for its numerous successes, perhaps most notably for the low per unit cost of these weapons, which less than a third of what was originally estimated based on historical figures ("Joint Direct Attack Munitions (JDAM)", n.d.).[7]

Program History

Following Desert Storm, both the Navy and the Air Force identified the need for precision, all-weather, aerial delivered warheads. The need was identified independently, but the efforts were quickly combined in 1991 into a joint program office. The JDAM SPO (System Program Office) has the Air Force as the lead service. From 1991 to 1993, the JDAM SPO operated in a very traditional fashion, with arms-length relationships between the SPO and the industry competitors during a down-select phase of the concept development. There were five competitors until 1994, when Boeing (then McDonnell Douglas) and Lockheed Martin (then Martin Marietta) were each awarded an 18-month contract for the first phase of Engineering and Manufacturing Development (EMD). Days after this award was made, the Office of the Secretary of Defense (OSD) designated JDAM one of five Defense Acquisition Pilot Programs (DAPPs). These pilot programs were to experiment with different ways of doing business, in the attempt to become more affordable.

Unique to many programs at this time, the SPO set up three internal groups. One to work with the Lockheed Martin team, one to work with the Boeing team, and a core Air Force team to remain neutral and mediate requirements between them. This set an early precedent of teaming relationships between the government and industry counterparts. Trust was established

[7] Historical estimates suggested a unit price $68,000, the target price was $40,000 for the first 40,000 units, and the bids from the competing companies when the contract was awarded were around $14,000 per unit (all figures in FY91$).

between the SPO groups and their contractors as both teams worked towards winning the competition. Though the competition was close, in 1995, Boeing was selected and awarded the contract for the second phase of EMD. In addition to working closely with the government, Boeing also worked closely with their suppliers. Estimates vary, but between 80-90 percent of the cost of the JDAM system is procured from suppliers and integrated by Boeing. Boeing quickly realized that in order to reduce the cost of their product, they would not only have to change the way they did business, but the way their suppliers did business, and the way they interacted with each other. For example, it was essential that Boeing work closely with its suppliers to lower the cost of the components of the guidance and control unit, which accounts for roughly 60 percent of the cost of each munition.

The program was in low rate production in 1998, just four years after it began. The weapon underwent operational testing in 1998 and 1999. During testing, more than 450 JDAMs were dropped, with a 95 percent system reliability, which was unprecedented (US Air Force, 2005c). The munitions were first dropped from the B-2 in *Operation Allied Force* in 1999. As production rates have steadily increased, development has also continued. The JDAM family has continued to expand since it's initial inception, integrating the tail kit on other dumb bombs (e.g. the 500 pound warhead), adding capability to the weapon (e.g. improving accuracy), or developing functionality to allow the weapon to integrate with more aircraft (e.g. the internal bays of the F/A-22).

The program is currently producing approximately 3,000 JDAMs per month, working on integration with eight new aircraft, and developing capability based on a technology roadmap through 2010 (Boeing, July 2005).

Program Execution

In addition to the teaming relationships with the government customer and the suppliers mentioned earlier, there are several other factors that allow the JDAM program to be successful. The government buys JDAM weapons based on a price commitment curve. This curve sets the prices for the weapon over several years, and although the contracts do not extend over the same time period, there is a standing agreement with the government to maintain order quantities (within a limited range) in order to receive the price indicated by the curve. Boeing then flows these long term pricing agreements down through to their suppliers. This provides negotiating leverage, and creates an environment where Boeing and their suppliers are willing to partner with each other, making investments and taking on risk, with the knowledge that the relationships are long-term.

The contract structure also promotes this partnership environment. Boeing meets their contract requirements by delivering a particular capability, not a particular design. Typically aerospace contracts are structured so the customer buys the design, not just the capability of the hardware or software. JDAM is different. Boeing maintains design authority for the system. This makes the government dependent on Boeing; they cannot simply cancel Boeing's contract, take the design to another contractor, and have them start up production (not that this is practical, but it the thinking behind owning the entire design). But it allows Boeing to substitute parts, change manufacturing processes, and develop new advancements allowing them to reduce costs, as long as the performance is maintained. Boeing does the same with their suppliers, allowing the suppliers (for the most part) to own the design. This creates some freedom for the suppliers that Boeing uses as an incentive to negotiate cost reductions in the product. This contractual relationship also creates dependency between the parties that is further incentive to partner towards success as opposed to individually optimize. From the customer through the suppliers, everyone is working towards performance specifications and price commitment curves.

Furthermore, three key suppliers participate in an Executive IPT, at the Vice President level of the organizations, with the Boeing Program Manager. This top management integration provides unified vision and leadership for the program.

In addition to the contract structure and the long-term pricing agreements, there are informal aspects of relationship building on this program. The relationships that have been established get lots of *"care and feeding"* from nearly everyone in the program, with particular focus from the leadership. Open communication and transparency are also critical for maintaining these close relationships. Communication is prevalent in this program, and it is obvious to even the most casual visitor. Boeing has set up web cams on their production floor so suppliers can see how much of their inventory has been used. This gives suppliers direct access and visibility into how the operation is running. It improves planning and is a strong indication of the trust between Boeing and their suppliers. The program has structured meetings to promote communication such as weekly teleconference meetings to discuss the program. But they also recognize the importance of meeting in person. *"It's important to have an appreciation for what they do – this requires meeting face to face in each other's environments."*

Throughout the program, lean principles and practices have been extensively implemented. The JDAM production facility is a showcase of efficiency. These practices have provided the program flexibility to scale their production volumes, and the continuous emphasis on reducing waste keeps the focus on maintaining a low unit cost. At the heart of the lean philosophy is emphasis on people. The JDAM program takes several unique approaches to developing their people. It is a small production operation with a unionized workforce, but from the receiving dock through assembly and test through packaging and shipping, there is only one job classification for all employees. This means that everyone who works on the production floor can do every job there is. Employees rotate through the positions on a weekly basis to provide variety. This cross-training not only motivates the employees, but it allows them to fill in for each other should someone be out sick or just need some help. In the office environment, JDAM keeps their engineers motivated by allowing them to do new and different work, even when the program does not have new work for them to do. For example, to keep some of their engineers fresh and energized, the JDAM program allows them to work special projects for other programs or the Phantom Works research and development group. This helps develop the engineers' skills, builds the network of contacts they interact with, keeps the engineers engaged in exciting work, and maintains their connection and loyalty to the JDAM program.

Sensor Fuzed Weapon (SFW) (1982-present)
Textron Systems, Wilmington, MA

Sensor Fuzed Weapon (SFW) is a smart area weapon designed to hit land and water-borne combat vehicles that are either stationary or moving. SFW is produced by Textron Systems for the U.S. Air Force. It is a 1,000 pound class air-to-ground munition consisting of 10 submunitions, each containing 4 Skeet Smart Projectile™ warheads, for a total of 40 warheads per weapon. Each Skeet Smart Projectile has a passive two-color infrared (IR) sensor and an active laser sensor, as well as a self-destruct and self-deactivation modes, ensuring a clean battlefield (Textron Systems, 2005). The SFW is combat proven and is currently certified on most of the fighters and bombers in Air Force inventory. SFW is primarily an anti-vehicular weapon, with the goal of producing "mobility kills" as opposed to destroying targets (Air Force Association, 1998). Because SFW delivers multiple projectiles over a wide area in one event, one of the many benefits of the SFW is that it can reduce the number of combat sorties that need to be flown to render an enemy force non-combat effective when compared to using other munitions for the targets.

Program History

Although the SFW program did not begin Low Rate Initial Production (LRIP) until 1992, the idea for the weapon predates the Gulf War. Development of SFW began in 1982 and lasted roughly ten years until LRIP began in 1992. It was originally conceived as a Cold War weapon for use against Warsaw Pact tanks. Based on the type of warfare seen in the Gulf War, it became quickly apparent that what had been envisioned as a Cold War weapon would be very useful against the newer enemy. The change in concept of operations (CONOPS) did bring some changes in requirements though. Most of the weapons dropped during the Gulf War were dropped from medium to high altitudes because there was no air-to-air threat and to avoid enemy air defense. During the Cold War the prevailing CONOPs originally planned that SFW would be dropped from low altitudes between 200 and 2,000 feet. The winds from 40,000 feet to the ground are very different from one altitude to the next and result in large and unacceptable delivery errors. This new requirement to deliver from up to 40,000 feet resulted in the development of the Wind-Corrected Munitions Dispenser (WCMD, pronounced "wick-mid") to maintain SFW performance at higher altitudes.

The program went into Full Rate Production (FRP) in 1996, and was first used in combat as part of *Operation Iraqi Freedom* in April 2003. As part of the program, there have been two Product Enhancement Programs (PEP1 and PEP2) to reduce the cost of the muntion. There have also been Pre-Planned Product Improvements (P^3Is), for example, one added the laser sensor, changed the warhead to be more lethal against a variety of targets including "softer" targets, and expanded the area the weapon covers. The program is currently producing around 300 weapons per year, working towards an inventory objective for the Air Force. The program is set to end when there are 6,500 SFWs in inventory. At the current production rates, this would occur in five to six years. The program follows pre-negotiated, long-term pricing agreements for future buys, but production is based on annual contracts. Each long-term pricing agreement is negotiated for four to five years. In 2006, the program is producing under the last year of the current pricing agreement and is working on negotiating a new one for production years 11-15 of production.

Program Execution

SFW represents the largest source of the business at the Textron Systems site in Wilmington, Massachusetts. It is the engine that drives the site. One of the unique aspects of the SFW program is that the current Program Manager has been involved with the program since the early 1980s. His long tenure on the program provides stability and a memory of the history of the program. Following his lead, the entire program is focused on communication. Because the Wilmington site for Textron Systems is relatively small (under 1,000 employees), quite a bit of communication happens in the hallways and in the lunchroom. Communication channels within the company are often based on personal networks. Outside of Textron within the program, communication is also emphasized, although through more formal systems. The SFW program at Textron has tailored points of contact for suppliers through Supplier Management and Procurement, for general program inquiries through the Program Manager, and for technical questions through the Chief Engineer. The individuals in these positions understand the importance of these communication channels. They reported spending hours interacting with their counterparts in customer or supplier organizations on a daily basis, often communicating with them a dozen or more times in a given week. These relationships, which bridge organizational boundaries, help keep the program integrated and working from the same set of information.

Like many other aerospace programs, about 70 percent of the material spend for the weapon goes to suppliers. The program includes about 100 total suppliers, but 35 of them account for 85 percent of the money spent. Critical Commodities Teams focus on these suppliers (among others). There are six Critical Commodities Teams engaged with SFW. These teams monitor the progress and the health of the suppliers through monthly meetings. Just as Textron has long-term pricing agreements with the Air Force for the weapon, Textron has long-term pricing agreements with their suppliers. For the most part these have worked out well, and in the cases where they have not, Textron has worked with the supplier to help make them successful. *"We don't want to do business with companies who won't make a profit – it makes them do stupid things."*

Standard Missile 3 (SM-3) (1996-present)
Raytheon Missile Systems, Tucson, AZ

Standard Missile-3 (SM-3) has a three-stage rocket, a kinetic warhead with an infrared (IR) seeker for hit-to-kill interception of short to medium range ballistic missiles. It is part of the Aegis Ballistic Missile Defense element of the Ballistic Missile Defense System (BMDS) for the Missile Defense Agency (MDA). MDA working in close coordination with the Navy and Naval Sea Systems Command (NAVSEA) is developing SM-3 to be launched from a standard launch system (MK 41 Vertical Launcher System) on a *Ticonderoga*-class cruiser or *Arleigh Burke*-class destroyer (US Navy Fact File, 2005b). The SM-3 builds on the SM-2 (Standard Missile 2) system, adding a third stage rocket motor, a GPS/INS (Global Positioning System/Inertial Navigation System) guidance section, and a kinetic warhead. SM-3 is one of Raytheon's largest programs, including more than 120 suppliers and four major subcontractors.

Program History

SM-3 was the Navy's entry into missile defense. With the support of a couple of enthusiastic Admirals, the Aegis LEAP (Light-weight ExoAtmospheric Projectile) Intercept program was initiated in 1996, and soon after it was designated SM-3. This initial effort was a sequential and evolutionary testing program involving seven missiles. This portion of the program is now referred to as Block 0. The first test occurred in 1999, and the first "all-up" test of the complete system was in 2002. Actually initiated in the 1980s, the LEAP project was an attempt to demonstrate miniaturized hit-to-kill technology. The SM-3 kinetic warhead grew out of this effort (Raytheon, 2005b).

Once the technology was demonstrated after the six year, Block 0 development effort, Block I began to develop and produce the first operational systems. Block I includes a total of 11 production missiles, several of which were delivered in 2004 and 2005. SM-3 follows a spiral development with Block IA, to be delivered in 2006, following Block I. Block II is essentially a completely different missile. It is a 21-inch diameter missile instead of the current 13-inch diameter. Utilizing the same kinetic warhead, the Block II munition will have more propulsion and a new guidance section. The target delivery date for Block II is 2010. Block IIA will follow Block II by adding a new kinetic warhead to the larger missile. Concurrently, there is also a technology development effort, the Japan Cooperative Research (JCR) program. This effort is a collaborative effort with the Japanese, and may feed into the Block IIA development program for the U.S. customer.

Program Execution

The SM-3 program relies heavily on a coordinated effort between suppliers and Raytheon. The Raytheon team has had fairly stable personnel, which has enabled close working relationships to develop. SM-3 has four major subcontractors who represent around 90 percent of the material spend, and 40 percent of the program dollars. Approximately 350 components come from another 120 or so suppliers. For a missile program, this is a large number of supplier relationships to manage. Because of the significant fraction of money flowing through the supply chain, these relationships are critical to the success of the entire program.

One aspect of the program that was heavily emphasized is a focus on meeting commitments. Accountability to the customer, the corporate parent, and suppliers, even to individuals in the organization is at the forefront of everyone's goals. The MDA customer drives a "must succeed" mentality on the program. In the mission requirements for this system, hitting the target is critical. This has become a focus on "hitting the target" in nearly every aspect of the program. In the minds of those on the program, success lies in meeting their commitments.

At the foundation of being able to meet commitments and fostering good relationships through the supply base is good communication. The SM-3 program relies on openly communicating information then trusting people to do their job. Information is seen as a one of the tools necessary for getting the job done. As such, many efforts are made to communicate throughout the program, either through direct one-on-one interaction, through established regular meetings, or through special all-hands sessions. This helps the program stay integrated as well as maintaining a teaming and flexible environment.

To support the sharing of information, sub-groups within the program periodically reorganize in order to ensure they are best supporting the program. A particular example of this is the recent shift in the systems engineering group from organization based on components of the system (e.g. guidance, kinetic warhead, etc.) to organization based on the system lifecycle (e.g. architecture, requirements, verification, production capability, etc.). This change allowed systems engineers a more holistic view of the missile system and it allowed them to prioritize between the various Blocks more effectively. From this new organization, the systems engineers can better support the other aspects of the program they interact with.

Spacecraft

Global Positioning System (GPS) IIF (1996-present)
Boeing Integrated Defense Systems, Huntington Beach, CA

Block IIF is the fourth generation of the Global Positioning System (GPS). GPS is a space-based system, providing location, time, and velocity information to military and civilian users worldwide. The GPS system essentially works by triangulating data between the user's unknown position and the known positions of multiple satellites. This requires several satellites to be in view of users worldwide at any one time. To achieve this, GPS consists of a constellation of 24 satellites in Low Earth Orbit (LEO). The constellation is constructed such that at least four satellites are in view of any point at any particular time (Jane's Information Group, 2005e).

The U.S. military acquires the system, led by the U.S. Air Force Space Command. The 50th Space Wing of the U.S. Air Force operates the system from Colorado Springs, Colorado. The system is currently capable of calculating time within a millionth of a second, velocity within a fraction of a mile per hour, and location to within 100 feet (US Air Force, 2005b). "GPS provides 24-hour navigation services including: extremely accurate, three-dimensional location information (latitude, longitude and altitude), velocity and precise time, a worldwide common grid that is easily converted to any local grid, passive all-weather operations, continuous real-time information, support to an unlimited number users and areas, support to civilian users at a slight less accurate level" (US Air Force, 2005b). In addition to the satellite constellation and the ground operations center, the system includes five monitor stations and four ground antennas located around the world to monitor and control the system (US Air Force, 2005b).

Program History

The system has a long history, dating back to the mid-70s when the concept was first explored. Eleven Block I satellites were used for proof of concept between 1978 and 1985 (12 were built, but one was lost during launch). Twenty-eight Block II/IIA satellites were launched between 1989 and 1997. These satellites formed the first 24-satellite constellation and provided the first operational system, which was available in 1995. Block IIA was a major design modification to add an auxiliary payload and fix a couple of other issues with the Block II design (Fisher & Ghassemi, 1999). Block II and IIA are grouped together as the second generation of GPS. The third generation of GPS is the Block IIR (R for replenishment). Block IIR satellites are meant to be more survivable than the earlier Block II/IIA satellites. They included capability to crosslink between satellites, allowing the constellation to autonomously update their navigation messages. This functionality allows the satellites to operate without ground contact for extended periods of time (Fisher & Ghassemi, 1999). Ten Block IIR satellites were launched between 1997 and 2003 (Jane's Information Group, 2005e).

GPS Block IIF (F for follow-on) will be the fourth generation system. In April 1996, a contract was awarded to Rockwell International (now Boeing) for development of the Block IIF system. First launch was supposed to occur in 2002, but due program restructuring and technical challenges, first launch is now expected for 2008 (Boeing, 2006a). The key design objective of the IIF system is to provide flexibility to incorporate changing needs and mission requirements. "With its built-in flexibility, GPS Block IIF represents a 'constellation of possibilities'" (Fisher & Ghassemi, 1999, p. 45). Block IIF achieves this flexibility through increased auxiliary payload capability, increased autonomy, and decreased operator workload, among other design features. More recently, additional capabilities have also been incorporated, such as, new civil and military signal codes and longer design life (Boeing, 2006b). The GPS IIF program is unique in combining the space and ground segment designs in one integrated program.

Although the basic GPS IIF design work began in 1996, development of the restructured modernization program occurred between 2000 and early 2006. A contract was awarded in November 2002 to begin building the first three Block IIF satellites. Six years between the beginning of production and first launch may seem excessive, but satellites are time intensive to both produce and test. Because satellites are largely inaccessible once they are launched, extensive testing is done on the ground. The first Block IIF satellite produced has just recently completed initial testing (Boeing, 2006a). Contract options to produce additional satellites (in groups of three) were awarded in November 2003, January 2005, and July 2006 (Boeing, 2003, 2005a). Production has been approved for the first twelve satellites. Although the original contract was to build 33 satellites, current expectations are for only 12 to be built (Jane's Information Group, 2005e).

Program Execution

Like many programs of the mid-90s, GPS IIF began in the era of "Acquisition Reform." During this time, the government was focused on acquiring systems "better, faster, cheaper." They were also open to innovative and different approaches to system specifications and contract requirements. In this light, the GPS IIF development began with a brief statement of objectives for the system instead of a lengthy statement of work for the contractor (Fisher & Ghassemi, 1999).

During this same period, the use of Integrated Product Teams (IPTs) gained popularity in aerospace. Block IIF was established with an IPT structure, including the contractors and the government customer in this structure. The integrated team-based environment allowed for close working relationships to develop between the major players in the development. Boeing as the prime contractor is responsible for system integration. This includes not only the space segment, which they are designing and producing internally, but also the ground segment, which Lockheed Martin and Computer Science Corporation are responsible for. Because of the size of Boeing and Lockheed Martin, the relationships can become complicated such that the two companies are partners on one generation or segment of the program and competitors for follow-on developments. For example, one division of Lockheed Martin is supporting Boeing in the development of the ground segment for the IIF program as a subcontractor to Boeing. That division and another division are competing with Boeing for the development of the next generation GPS III space and ground systems. At the program level, Lockheed and Boeing work well together, knowing partnership is the best thing for both organizations as well as the customer.

Complicated internal relationships in the program are not restricted to different companies. The IIF program group at Boeing Huntington Beach is focused on design, program management, and integration. They rely on sister Southern California sites within the same Boeing Networks and Space Systems business unit to assemble, integrate, and test the satellite. The resources dedicated to this program at the sister sites are nearly five times that of the main IIF program group. The IIF program is largely an integration effort in addition to satellite and ground system development. Program managers have often found themselves spending nearly half of their time working with customers, partners, and suppliers in the course of executing the program.

Of course, internal focus is also important. The GPS IIF management work to maintain a "safe" atmosphere in the program. This feeling of security encourages engagement in the work, promotes open communication, gets people moving in the same direction, and cultivates trust and respect. This environment is maintained through all hands meetings, roundtable forums, and asking lots of questions and not shooting the messenger for delivering an answer that is unexpected. These practices are strengthened through regular assessment of their program management practices. Both self-assessment and independent assessment of program management practices are used as a tool to help the program improve their execution. These assessments lead to action plans that are integrated into the strategic goals of managers throughout the program. An important caveat to these internally focused approaches is that they generally do not spread across organizational boundaries within the program. On the GPS IIF program, they may work well in one organization, but they are not shared across the entire program.

Globalstar (1991-2000)
Space Systems/Loral and Globalstar LP, Palo Alto, CA

Globalstar is a satellite service system providing voice and data connection through a constellation of Low Earth Orbiting (LEO) satellites, land-based gateways, existing cellular phone networks, and handheld phone units. Globalstar uniquely combined a LEO satellite constellation designed by Space Systems/Loral with Qualcomm's CDMA (Code Division Multiple Access) technology to provide these services. Globalstar phones can access the satellite, existing digital cellular, or analog cellular networks.

Globalstar service is currently in operation, with Space Systems/Loral contemplating plans for a new constellation to replace the existing satellites which, after being launched between February

1998 and February 2000, are nearing the end of the their design life of seven and a half years. Globalstar's constellation consists of 48 satellites and four on-orbit spares that cover approximately 80 percent of the earth's surface in a band north and south of the equator. Because of the satellite orbits, the Polar regions of the Earth are not covered.

The Globalstar system works by linking the user's phone to multiple satellites. These satellites simply bounce the signal back down to a land-based gateway that connects to local telephone networks where the call is to be received. This architecture simplifies the satellite design because it does not require any inter-satellite links. This design requires partnership between Globalstar and local gateway operators. This makes the challenge of managing all the stakeholders of the system more complicated.

Globalstar is currently operating in over 120 countries worldwide (Globalstar, 2006), and although the market has not developed as anticipated, the service has recently found a market in emergency preparedness and response.

Program History

The Globalstar concept grew out of a research and development group at Space Systems/Loral responsible for "wild card" developments. This group pursued the new technology aspects of business development. The idea of using LEO satellites was relatively new at the time, but had been proven with the Global Positioning System (GPS), which had already been fielded. Although Space Systems/Loral could develop the space-based portion of the system, they did not have experience with the other aspects of the system. They sought out partnership to help with the communication link and handset technologies. Initiated in 1991, the parent organizations Loral Corporation and Qualcomm Inc., formed a joint venture, Loral Qualcomm Satellite Services Inc. to develop the Globalstar system (Jane's Information Group, 1993a).

During the first three years, the system design work was largely completed with a small team of around 30 people.

In 1994, Globalstar LP was announced, including eight other companies: AirTouch Communications, Alcatel, Finmeccanica, DACOM, DASA, France Telecom, Hyundai, and Vodafone. Even though there was an extensive group of organizations participating in this limited partnership, Space Systems/Loral acted as the system integrator in the arrangement. The headquarters for Globalstar LP were moved out of Space Systems/Loral offices to their own facility. These additional players represented partners for detailed design and production, as well as service providers throughout the world. Partnership was an important aspect of the Globalstar system.

The total system development took about nine years, and by February 1998 the first satellites were being launched. In November 1999 the service was launched to a small group of preliminary users, and just a few months later in February 2000, full commercial service was launched across North America. By February 2000, the full constellation of 52 satellites had been launched successfully.

Globalstar initially expected half a million subscribers and half a billion dollars in revenue. By early 2001, a year after service launch, they had only around 13,000 subscribers and around $2 million in revenue (Hesseldahl, 2001). The subscription rate did not improve rapidly, and in February 2002, Globalstar filed for Chapter 11 bankruptcy. After bankruptcy, in late 2003, the acquisition of Globalstar LP by Thermo Capital Partners LLC was approved. One of the largest current uses of the Globalstar system is by U.S. military troops stationed overseas, in places like Iraq, with little national infrastructure.

Program Execution

Partnership was critical on the Globalstar program. The design of the system necessitated active engagement by many different organizations in order to make the system successful. The development of various system components was broadly distributed, but their functionality was integral to system performance. For example, Qualcomm used the Globalstar program as an opportunity to develop their CDMA technology as part of the ground station development. When this development took longer than expected, the entire system was captive to the Qualcomm schedule.

There were other issues related partnerships that affected the program execution as well. For example, although Space Systems/Loral never did any military work, they used rigorous, "defense-like" practices to ensure the reliability required for space system development. This requires extensive documentation and testing, among other things. Qualcomm on the other hand used different business practices, and had little understanding or appreciation for what appeared to be the very rigorous specifications Space Systems/Loral was imposing on them.

In addition to the differences in business practices, there were cultural differences between the organizations spread out around the world. These international relationships were important to securing local support for the Globalstar system in order to be able to operate worldwide, establishing land-based gateways, and using local networks. Managing these relationship took significant effort. This global partnership was developed by having monthly meetings at different sites around the world to ensure everyone had a sense of solidarity and stayed engaged with the program. Managing this international consortium of partners took up nearly a third of Globalstar's President's time and nearly half of the Executive VP for Marketing's time. Clearly the partnerships were critical to success of the system, and the executives put in the time and energy to ensure they worked smoothly.

Another interesting aspect of the partnerships was the impact of individual relationships. For example, when the contract was negotiated between Loral and Qualcomm, the terms were essentially set during a phone call between the Chairmen of the two companies. The formal negotiations were sidelined and the contract was drawn up based on the agreement between the executives. In another example, the relationship between Space Systems/Loral and Qualcomm was challenging during the development of the system. *"The relationship started as agreement in principle, but during implementation, working together was hard."* Space Systems/Loral eventually decided they needed to know more about what Qualcomm was doing. Qualcomm was very cautious about protecting trade secrets and had no interest in outsiders inside their plant. As it turned out, the Program Manager at Qualcomm and the Chief Engineer from Space Systems/Loral had ties from college. The President of Globalstar was open to using relationships outside of the formal organization chart and he took advantage of the collegiate connection to literally get in the door at Qualcomm. The existing trust between the Qualcomm Program Manager and the Space Systems/Loral Chief Engineer provided an entrée for establishing a working relationship between the two organizations that otherwise would have been impossible, given the significant differences between the two companies.

Iridium (1988-1999)
Motorola Satellite Communications and Iridium, Inc., Chandler, AZ

Iridium is a communication system, consisting of a constellation of 66 satellites, land-based gateways, and handheld phone devices. Together they form a network to provide voice and data transmission around the world. Iridium was envisioned as an answer to the problem of limited coverage in land-based cellular telephone systems. The satellite constellation provides full coverage of the Earth's surface. The Chief Engineer of the project once described, "Iridium is much more than the technology that allows it to be built – Iridium is a vision, a realizable vision, for a worldwide portable, personal communications system – a vision whose greatest realization, like the telephone of a century ago, are beyond today's imagination" (Leopold, 1992, p. 451).

Iridium began as a Motorola project, and in many ways, the concept of Iridium fit in well with the innovative history of the company. Motorola pioneered FM radios, semiconductor products, paging systems, cellular phones, and space communication transponders (Leopold, 1992). They had no shortage of experience in the communications area. Motorola combined their innovative concept for a worldwide communication system and their experience with highly reliable manufacturing with Lockheed Martin's expertise in satellite design, and a number of other partners for support around the world, from launch vehicle partners in Russia and China, to regulatory agencies and financial backers in other countries. "Iridium's foremost challenges are not in technology – the regulatory and licensing aspects of a truly-worldwide, portable radiotelephone service are clearly the more dominant issue" (Leopold, 1992, p. 453).

Iridium was a $5 billion project with some impressive feats achieved along the way. During the execution of the program, the development, production, and deployment of the system was completed more than a month ahead of schedule. This included building 100 satellites, and launching 72 of them to begin initial service. The 72 satellites were launched in 12 months and 12 days, from May 5, 1997 to May 17, 1998. This was accomplished through 15 consecutive successful launches, including one period where 14 satellites were launched from three different launch vehicles in three countries in a 13 days. The almost frantic pace of satellite deployment is representative of the whole program that relied on holistic system thinking, rewarded innovation, leveraged experience, and generally had a *"it can be done, how can we make it happen"* attitude.

Program History

Three engineers, working as part of a group of systems thinkers specifically charged with developing new opportunities for Motorola, developed the concept for Iridium in 1987. A year later, in 1988, the concept was presented to the top executives of Motorola during an annual operating review. These reviews included an opportunity for "minority reports" of new technologies that were more risky, less mainstream, and even a bit harebrained. In August 1988, when the idea was presented, the executives did not want to loose the idea; in fact they decided to take it to the Board of Directors. They spent the next year refining the concept, exploring regulatory hurdles, and developing a strategy for the project. In November of 1989, Motorola made the decision to put the first significant investment into the project, creating a new Strategic Business Unit, Motorola Satellite Communications. At this time, the company held the project closely, and even within Motorola it was hidden as a secret project, thought by many to be a classified project for the government. Up through this point, the team working on Iridium was small, building to around 25 people by early 1990.

The first public announcement about Iridium was made in June 1990. The announcement was made primarily because the program had to begin working with regulators and investors. A year later, in 1991, Iridium, Inc. was formed as a stand-alone entity. During this time, the ramp up in staff exploded and the program grew by an order of magnitude to nearly 300 people. Between 1991 and 1992, the design was reviewed, refined, and the architecture was finalized so that in July 1993, a five-year development, production and deployment contract began. By this point, the program had grown dramatically, to close to 3000 people. In 1996 the first satellites were built, and the satellite design was qualified. In 1997, the control center was opened, and in 1998 12 gateways were put in place.

In total, the program produced 100 satellites; 95 of them were launched into orbit, four were used in the qualification testing, and one is hanging in the Smithsonian (Leopold, 2004). As mentioned previously, 72 satellites were launched between 1997 and 1998. Demonstration calls were made in April 1998, and initial service began in September of 1998. In June 1998, the CFO of Iridium indicated they needed 600,000 subscribers to begin paying down debt. The company predicted they would reach that milestone by the end of 1999. They also projected reaching five million subscribers by 2002. This would have led them to an estimated $6 billion per year revenue (Anselmo, 1998). In reality, Iridium did not come close to approaching these projections, and they filed for Chapter 11 bankruptcy in August 1999. In 2000, Iridium Satellite LLC bought the physical assets and intellectual property of Iridium for fire-sale prices. As indicated in the Washington Post, "For half a penny on the dollar, Iridium Satellite LLC has snapped up $5 billion of assets of the failed Iridium LLC, giving its new investors hope that the bankrupt satellite phone company will turn a profit for the first time. For $25 million, the new, privately held firm essentially gets to start over, debt-free, and has sketched a new plan for a global satellite phone service, raised from the ashes of one of the most spectacular business failures in recent memory" (Noguchi, 2000, p. E5). By 2000, Iridium had only sold 63,000 phones, but they got a jump-start on the new business with a large Department of Defense (DoD) contract for 20,000 phones and service. Since it's inception, and perhaps learning from the overly optimistic mistakes of the old company, the new Iridium, has targeted niche markets including, aviation, construction, disaster relief/emergency, forestry, government, leisure travel, maritime, media & entertainment, military, mining, oil & gas, and utilities (Iridium Satellite LLC, 2006).

Program Execution

Despite the bankruptcy and business failure of the original Iridium company, there were many things the Iridium program executed successfully. These aspects of the program are often overshadowed by the business results, but they are worth discussing. In many ways, the Iridium program faced difficult socio-technical challenges, and there are lessons to be learned from the strategies the program utilized. From its inception at Motorola, the Iridium program had a team-based culture. The engineering team created a shared vision of "Personal Communications – Anyone, Anywhere, Anytime" (Leopold, 1992, p. 451). Lockheed Space and Missile Corporation was selected as the satellite bus supplier and Raytheon for the satellite antennas (Jane's Information Group, 1993b). Once these two organizations were on board, they quickly became enmeshed in the program and it was near impossible to distinguish which company someone worked for. There was a clear focus on placing the program and the system as the top priority.

Another important strategy the program used was system-level management. The Motorola group originally envisioned themselves as a small, system-level organization for integration and management. They subsequently realized that this structure was appropriate for the early phases of conceptual design, but it would not work for the detailed design and production phases. The program continually readjusted their organizational structure to match the type of work they were doing and the phase the program was in. Although the system-level organization was not the right solution for the duration of the program, it did lead them towards other system-level management approaches that were useful. One such example is the how the program managed all "margin" in the design at the highest system level. Design margin is the difference between what is available in a budget and what is used. Usually, design margins start out fairly high in the conceptual phases, and as the details of the design get worked out, the margin gets used up. In design, the margin is often rolled down to the component level, for example, a power margin for the system gets divided between various subsystems with power requirements, and then it is further divided between components of these subsystems. In the Iridium system, all design margin was held at the system level. This meant that trade-offs could be made at the system level. If one part of the system needed to go beyond their allocation and eat into the margin, the impact to the whole system could be assessed. In addition to the design margin, management reserve of schedule and budget were also held at the system level, allowing for similar trade offs to be made if one part of the system was ahead or behind of schedule or over or under cost.

Part of the strategy of system-level management necessitated hiring senior, very experienced people to work on the program. These people generally have a more holistic, systems perspective and are able to draw from their experience to consider high-level decisions. When Iridium began hiring, they initially looked for candidates with 15-20 years experience. This was not an entry-level job. The cumulative years of experience of the program team helped them face the challenges of the program realistically, while still allowing for creative and innovative approaches.

In that regard, it is important to appreciate the significance of good context. The Iridium concept fit in with Motorola's history of innovation in communication systems. The idea was conceived and nurtured in an environment where creativity was encouraged. The beginning of the program coincided with the end of the Cold War and a downturn in defense spending in the early 1990s. The decrease in work on the defense side of the aerospace industry meant there was no shortage of experienced talent looking for opportunities. Iridium was also not hindered by defense contractor business practices. Although Motorola did some work for the government, Iridium was a commercial venture. Commercial business practices, in general, do not include the same rigorous oversight required by the government customers. This gave Iridium some flexibility it would not have had if it had been developed as a defense system. All in all, the context of the Iridium development had an impact on how successfully the program was executed. In some regard, it was the case of the idea being hatched in the right place at the right time. This combined with a true system-level management strategy and a team-based environment, allowed for program execution that is impressive by any standards. Unfortunately, the initial failure of the system as a viable business will forever haunt the Iridium name.