Lean Aerospace Initiative (LAI)
MIT Research Studies
Applicable to Systems Engineering

Last Updated: June 2004

This publication contains abstracts for past research thesis projects related to systems engineering completed within the LAI research group at Massachusetts Institute of Technology. Links are provided to the full thesis documents.
LAI Website: http://lean.mit.edu/

If this report was useful to you, we would appreciate your feedback and comments.

Points of Contact:
- Dr. Eric Rebentisch, erebenti@mit.edu
- Dr. Donna Rhodes, rhodes@mit.edu

TABLE OF CONTENTS

ENGINEERING PROCESSES

System Architecting

An Analysis Method for Conceptual Design of Complexity and Autonomy in Complex Space System Architectures
Brandon C. Wood, 2001

Recent research by the Massachusetts Institute of Technology (MIT) Space Systems Laboratory has demonstrated a system engineering and architecting framework that enables the creation and quantitative comparison of numerous, unique space system architectures. The foundation for this method is the belief that all satellite systems are information disseminators that can be represented as information transfer networks. This paper uses that work as a foundation and addresses its inadequacy in accounting for the more difficult to quantify operational issues associated with space systems. The Lean Aerospace Initiative, in concert with the Space Systems, Policy, and Architecture Research Center, supported this research.

The first phase of this research involved a series of structured interviews with major civil, defense, and commercial satellite manufactures. System engineers, at a variety of organizational levels, were questioned about the current set of techniques used to evaluate spacecraft command and control system designs. In addition, data was collected on how operational concerns were addressed in the conceptual and preliminary design phases of development. This results shows that operational issues, although beginning to play a significant role in preliminary space system design, do not play a significant role in conceptual space system design. These interviews supported the development of an operations complexity metric that can be used to evaluate intelligent command and control schemes in complex, multi-satellite space systems.

A space mission was studied, in the second phase of this research, using the previously demonstrated system engineering and architecting framework but with the inclusion of the new operations complexity metric to compare different architectures. The space system's mission was to collect data on ionospheric disturbances for use in ionospheric weather forecasting. A computer model was developed that produced a frontier of optimal space system architectures given the specific objectives of the satellite constellation.

This effort has developed and demonstrated an operations complexity metric to expand the viability of quantitative space architecture analysis. This metric is robust enough to accommodate advanced command and control technology, such as software agents, that are poised to revolutionize space operations and enable highly autonomous constellations of satellites. The use of the metric showed that it quantified operational issues with relatively easily collectable data, minimized misinterpretation of the design method, and relied on reasonable assumptions.

A Partitioning Methodology for Helicopter Avionics System with a focus on Life Cycle Cost
Leon M. Silva, 2001

Traditional system engineering methods rely on decomposition for establishing system partitions. As one of the key responsibilities of a system architect, the decisions made with respect to how an avionics system is partitioned play a significant role in the system's Life Cycle Cost (LCC). Despite this, most of the decomposition methods available focus on managing the complexity of the system with respect to the architect's ability to understand the system. In other words, the method is designed to keep the complexity of the system below the architect's inherent threshold limit of understanding. Given the impact that the partitioning process has on the system's LCC, it seems appropriate to derive a methodology that takes into consideration not only complexity but also other critical factors.

A framework was developed in order to quantify and compare the reliability and maintainability of five different helicopter avionics system architectures. The information was extracted from actual data

collected during the maintenance of the five helicopter systems used by the US Government over a period of two years. Based on these five case studies, a set of partitioning criteria was developed that can be used in future programs in order to improve the LCC of the system.

The methodology provides a process whereby the analysis of maintenance data can assist the system architect in making better architecting decisions. The process identified some compelling issues with respect to data available in this area. There are significant limitations in the current maintenance infrastructure that need to be resolved to a greater extent before this method can be more generally applied. The process also identified some additional factors that have an impact on the LCC. The most compelling was that of legacy subsystems that offer significant problems with respect to their partitioning due to the fact that they are more entrenched in the current avionics market.

Chains of Function Delivery: A Role for Product Architecture in Concept Design
Timothy W. Cunningham, 1998

This research intends to improve three areas of team performance in concept design: the team's understanding and recognition of the product architecture, the team's ability to document integration issues and risks, and the team's ability to judge whether a product concept is worthy of further pursuit. Many of the high-impact decisions made in concept design revolve around integration issues: how the product's physical elements work together to deliver the performance characteristics, or functions. The product architecture, a singularly important characteristic of the product, is in great part determined by the mapping of the product's functions to the physical elements that deliver those functions. Integration issues pose a unique kind of integration risk: the chance that adequately designed individual elements will not function properly when connected to form the product, or cannot be assembled and debugged easily and quickly. During concept design, a development team must recognize integration issues in the functional-physical mapping so they can assess the associated integration risk, and judge their concepts on this basis. Since information is weak and fragmented during concept design, performing a formal analysis of the problem is a significant challenge.

In addressing this problem, the thesis begins with an explanation of the conflicts between the design theory representations of how architecture is created and real issues faced in product development. Specifically, many decisions encountered by a multi-disciplinary development team are made in the physical domain and influence the decomposition, altering the functional-physical mapping. Because the theory does not allow for physical decomposition, this part of the mapping goes undetected in current approaches. Integration issues and conflicts often result. This thesis expands the current theory by creating a framework for architecture that allows for decomposition choices of this type.

Given this theoretical framework, two themes are explored. First, a systematic procedure for identifying integration issues in mechanical assemblies is developed. The procedure captures chains: graphical representations of how product-level attributes are delivered, depicted on a hierarchy of the physical elements. Chains, which differ for each concept and decomposition, show 1) which functions are delivered in integral fashion, and 2) which elements play a role in delivering each function. Represented graphically, chains can help the multi-disciplinary team relate the diverse technical and non-technical influences on decomposition and architecture.
Metrics can then be applied to reveal the integration issues and integration risk associated with many, potentially conflicting chains. The research applies established part locating mathematics in the procedure, expanding the utility of this existing idea by applying it to concept design. Second, the thesis develops a method for conducting a chain analysis of candidate concepts and decompositions, creating a framework for trade-offs in the context of architecture. The method and chain procedure and metrics are tested on a real, complex, integral product, the Lockheed Martin Joint Strike Fighter military aircraft, to assess their utility.

Requirements Engineering

Best Practices In User Needs/Requirements Generation
Joseph Robert Wirthlin, 2000

An idealized process framework for the front-end of product development was developed. The framework covers the process space from an initial need (or recognition of a need) to the decision for a product/development program launch. The framework focuses on the activities required for the development of requirements needed for a business case decision. The framework was developed through a thorough examination of the literature relating to product development and addresses not only the activities required to traverse the front-end of product development, but also metrics and a process maturity matrix by which an organization's process can be evaluated.

Using case studies of the front-end processes of eight commercial organizations and eight military organizations in addition to the US Air Force, the applicability of the framework was tested. All of the organizations demonstrated the existence of the four fundamental activities contained in the framework but a discussion of the existing process enablers revealed various interpretations of required features. The maturity matrix was used to evaluate each of the organizations (commercial and military) relative to an idealized and mature front-end process. The analysis revealed a significant gap between commercial and military process performance. Additionally, the existence and application of the process enablers was significantly correlated with the organization's performance in the four process activities of the front-end framework.

The implications of the research indicate that military organizations in general will need to reevaluate the current practices in the front-end and the application of process enablers within their organizations. Further, military organizations should reexamine if the current process structure for system development in the front-end needs significant changes.

Identifying Lean Practices for Deriving Software Requirements
Brian J. Ippolito, 2000

Lean principles focus on employing value added activities to reduce product development cycle time, increase quality, and reduce cost. Lean originated in the automotive industry and has since been centered in the manufacturing domain. Lessons learned on implementing Lean initiatives have been captured by the in the Lean Aerospace Initiative (LAI) and incorporated into the Lean Enterprise Model (LEM) (http://lean.mit.edu/public/index.html). To the author's knowledge, this is the first research effort specifically designed to apply the Lean principles and the Lean Enterprise Model to the aerospace software requirement derivation process.

Data supporting this research is the result of a comprehensive two-year research effort involving three detailed case studies with 45 case study interviews, 125 stakeholder surveys collected from ten aerospace software upgrades, feedback from numerous aerospace industry practitioners and Massachusetts Institute of technology (MIT) faculty.

Ten aerospace software upgrades were analyzed at both an enterprise level and an organizational level to identify the presence of Lean practices. At the enterprise level, metrics typically used to measure enterprise performance (Flow Time, Stakeholder Satisfaction, Quality Yield, and Resource Utilization) were found to be appropriate for the software requirement process but not adequately implemented. An organizational analysis observed five of the twelve Lean practices as effectively implemented and identified opportunities to implement four more Lean practices.

Identifying the Impact of Modeling and Simulation in the Generation of System Level Requirements
Myles A. Walton, 1999

Requirements generation is an influential time in the evolution of the program. It allocates 70% of the life-cycle cost of a program and is responsible for a large percentage of the system errors and cost overruns. This project lays the framework of the current state of requirements generation and then focuses on the use of modeling and simulation within the process. It is shown that although modeling and simulation tools are being used extensively in requirements generation in many programs throughout the DoD, their effectiveness is largely undocumented and areas of high leverage are unknown. Research results also indicate that the more effective use of M&S within requirements generation could be achieved with increased tool interoperability and easier tool validation and verification. Finally, the ability to perform more iteration early and M&S use as a boundary object for communication are set forth as the two main benefits of M&S.

Integration Testing

Opportunities for Lean Thinking in Aircraft Flight Testing and Evaluation
Carmen Carreras, 2002

The application of Lean principles and practices has been shown to help aerospace companies reduce waste and maximize value to help meet the changing demands of the market. The most visible area of influence has been manufacturing, where great strides have been made in cost and cycle time reduction. Recently, the flight testing community has been faced with similar challenges. This paper investigates whether Lean principles can be applied to aircraft flight testing and evaluation to help meet these goals. Specific objectives are to identify opportunities for the implementation of Lean thinking and establish a framework for structured implementation of Lean principles and practices.

This study focuses on seven aircraft programs: 737-NG, 767-400, Hawker Horizon, F-22, F/A-18E/F, C-130J, and the T-6A. The programs are analyzed from a programmatic viewpoint to identify where lean practices are currently being used and how lean thinking could further improve the overall flight testing process. Additionally, a detailed examination is performed on the day-to-day activities to identify the daily sources of waste and their impact on the program. The detailed analysis focuses on flutter testing as a surrogate for the entire testing program. A total of 90 flights were analyzed.

Data collected from the case studies fits well into the value-creation framework established in *Lean Enterprise Value*. Each of the phases of the framework – value identification, value proposition, and value delivery – are discussed as they relate to flight testing. Many examples of the application of lean principles and practices as well as opportunities for implementation are presented in the value delivery phase. Opportunities were identified in: coordination of the systems engineering value stream, coordination with other test aircraft and necessary support functions, and management of the daily test operations.

This preliminary study indicates that Lean thinking can be applied to flight testing. The guiding principles of well-run testing programs paralleled those of Lean. Additionally, there are many instances where Lean thinking would provide an opportunity to eliminate waste and improve efficiency.

Trade Study Analysis

Tools for Evolutionary Acquisition: A Study of Multi-Attribute Tradespace Exploration (MATE) Applied to the Space Based Radar (SBR)
Timothy J. Spaulding, 2003

The Multi-Attribute Tradespace Exploration (MATE) process was applied to the Space Based Radar (SBR), a space system under study by the United States Air Force. A system-level model of possible SBR architectures was created using data and analysis from previous high-level studies. Competing designs were evaluated through MATE's universal utility metric.

The MATE model was qualitatively compared against a high-level design study and MATE's advantages were noted, specifically its ability to trace modeling assumptions and present a holistic view of the space of competing designs. A quantitative comparison revealed significant differences between MATE's recommended system design and that of the comparison high-level study.

The potential for a simplification of the MATE method was explored through the use of several approximations to revealed user preferences. Comparisons were made through both a proportional utility loss metric and a general Spearman's Rho rank order correlation. Using these measures it was shown that while a linear or subjective approximation to utility curves resulted in excessive errors, and approximation to weighting relationships did not.

Finally, MATE's potential applicability to the Air Force acquisition process was studied. In general MATE was shown to be useful to any acquisition effort that derives its benefit from a networked approach and is of sufficient technical complexity as to make tradeoff decisions opaque to casual analysis. Specifically, MATE was shown to be useful in the analysis of alternatives process as well as an aid to early milestone sourcing decisions.

Multi-Attribute Tradespace Exploration and its Application to Evolutionary Acquisition
Jason E. Derleth, 2003

The Air Force has recently embraced Evolutionary Acquisition (EA) as its acquisition strategy of choice. EA is an especially difficult method of acquisition and presents some extraordinary challenges at the system engineering level.

Multi-Attribute Tradespace Exploration (MATE) is a tool at the system engineer's toolbox that can provide some focus on a project in EA. MATE, a tool initially developed by Adam Ross and Nathan Diller at MIT, is a method of developing models to simulate the product user's preferences for the attributes of a design. Once these preferences are well known, they can be used to guide the design choice.

The design choice is further guided by the creation of system level computer models that represent the design choices available to the engineer. These choices are then varied systematically to create a "tradespace" of possible designs. This tradespace exhaustively enumerates all of the possible design choices for the engineer. Then, through the preference models previously developed, each possible design is ranked in order of user utility and cost. The result can be graphed, giving a visual representation of the utility and cost of literally thousands of architectures in a single glance.

This thesis shows that MATE is a useful tool for a systems engineer working on an EA system. There are many benefits to the use of MATE in EA, including but not limited to: a better understanding of the end user's desires and requirements for the system; the ability to optimize the system for the first evolution; the possibility of understanding what will become optimal in later evolutions; quick redesign time if circumstances or preferences change; and further insight into systems level considerations.

In addition to showing some of the benefits of MATE, this thesis furthers the application of MATE itself into systems not involved with space. Previously all applications of MATE had been concerned with space systems.

Multi-Attribute Tradespace Exploration with Concurrent Design as a Value-Centric Framework for Space System Architecture and Design
Adam M. Ross, 2003

The complexity inherent in space systems necessarily requires intense expenditures of resources both human and monetary. The high level of ambiguity present in the early design phases of these systems causes long, highly iterative, and costly design cycles, especially due to the need to create robust systems that are inaccessible after deployment. This thesis looks at incorporating decision theory methods into the early design processes to streamline communication of wants and needs among stakeholders and between levels of design. Communication channeled through formal utility interviews

and analysis enables engineers to better understand the key drivers for the system and allows for a broad and more thorough exploration of the design tradespace.

Multi-Attribute Tradespace Exploration (MATE), an evolving process incorporating decision theory into model and simulation-based design, has been applied to several space system projects. The conclusions of these studies indicate that this process can improve the quality of communication to more quickly resolve project ambiguity, and enable the engineer to discover better value designs for multiple stakeholders. Sets of design options, as opposed to point designs, in addition to the structure of the solution space can be analyzed and communicated through the output of this process.

MATE is also being integrated into a concurrent design environment to facilitate the transfer of knowledge of important drivers into higher fidelity design phases. Formal utility theory provides a mechanism to bridge the language barrier between experts of different backgrounds and differing needs (e.g. scientists, engineers, managers, etc). MATE with Concurrent Design (MATE-CON) couples decision makers more closely to the design, and most importantly, maintains their presence between formal reviews. The presence of a MATE-CON chair in the concurrent design environment represents a unique contribution of this process. In addition to the development of the process itself, this thesis uses Design Structure Matrix (DSM) analysis to compare the structure of the MATE-CON process to that of the NASA systems engineering process and that of a U.S. space company to gain insights into their relative temporal performance. Through both qualitative and quantitative discussions, the MATE-CON process, which is derived from the fundamental concept of engineering, is shown to be a “better” method for delivering value to key decision makers.

Decision Analysis

Space Launch Operations and Capacity Modeling: A System Dynamics Methodology for Advanced Analysis of the U.S. Eastern Range
David H.W. Steare, 2000

A prototype computer model was developed to assess the feasibility and potential benefits of a system dynamics approach to calculating space launch operational constraints and range capacity. This research effort concentrated on modeling the U.S. Eastern Range. The current U.S. Air Force Range Capacity Model served as a modeling framework, upon which significant enhancements of analysis capability and fidelity were achieved. Improvements realized by the system dynamics methodology are due to a fundamental transition in modeling technique from a deterministic spreadsheet approach, as utilized by the Air Force, to a more realistic simulation platform. The system dynamics model produces a probabilistic distribution of values rather than a single point solution and does not require the input of an annual launch manifest.

In addition to developing an improved modeling methodology, two analyses of Eastern Range operating conditions were conducted for fiscal year 2001. The first analysis examined the expected operating conditions. The second analysis focused on operating the range under a maximum launch capacity scenario. In comparison to the 30 launches scheduled on the Eastern Range manifest, simulation results suggest range launch capacity as a distribution of values between 49 and 54 launches, with a mean value of 51 launches. Even though the FY01 launch manifest will not utilize the maximum capacity of the range, the model predicts that launch programs will still collectively endure approximately 2,500 calendar hours of wait time before range resources are available to fulfill all requests for range support. The following six range constraint categories were modeled as the primary causes of the unavailability of range support resources: 1) range crew rest, 2) planned restricted periods, 3) range lockdown, 4) rescheduling impact, 5) unexpected range systems maintenance, and 6) single major operation support capability. Range crew rest was determined to have the largest detrimental impact to launch operations efficiency for both the FY01 expected operating conditions and the launch capacity scenario. The relative impacts of the remaining five categories were observed to fluctuate depending on the number of launches and resulting congestion of range operations.

System/Product Design

Stakeholder Collaboration in Air Force Acquisition: Adaptive Design Using System Representations
Robert E. Dare, 2003

Air Force development of new or evolutionary weapon systems is a complex endeavor due to the involvement of many stakeholders and the presence of considerable uncertainty in the acquisition environment. The ability to adapt a weapon system while it is still being designed affords a means to respond to this complexity. The fundamental motivation for this research is to discover how Air Force development programs, operating within established constraints, can improve their adaptability during the design phase to provide more value to the warfighter.

The thesis of this research is that the quality and nature of collaboration between stakeholders during the design phase of weapon system development programs determines how effectively they share knowledge, which in turn drives the level of program adaptability.

Eight case studies were conducted on Air Force development programs. Data were collected on collaborative practices and patterns of adaptability demonstrated during design. The research placed an emphasis on usage of "system representations" such as prototypes and beta software releases that acted as a form of boundary object to facilitate knowledge sharing across organizational boundaries.

As programs used system representations to provide higher levels of knowledge sharing, they were found to be more adaptable. System representations were more effective at promoting adaptability when they represented the design with higher fidelity, providing system-level detail and covering stakeholder emphasis areas. Lastly, certain key stakeholder roles were found to contribute both flexibility and structure, facilitating a "zone of novelty" in which the stakeholders could exercise creativity and evaluate design options while still executing the program within established constraints.

This research indicates that the pressing need for Air Force programs to be able to adapt in today's uncertain acquisition environment can be addressed to a significant degree through the usage of effective system representations in conjunction with supporting patterns of stakeholder interaction. Specific recommendations for Air Force acquisition policy makers and practitioners are provided.

Strategies for Dealing with Instabilities in a Complex, Multi-Project Product Development System Engineering Environment
Michael R. Wright, 2003

This thesis evaluates the product development process from the perspective of a multiple gas turbine engine development programs. The risk to meeting cost and schedule requirements has increased solely due to squeezing budgets and schedule to fit the "better, faster, cheaper" mold. The thesis focuses on the further risks to cost and schedule of the gas turbine product development cycle that are caused by instabilities introduced by the cyclical nature of multiple product development programs completing the cycle and new ones starting. Market and business factors influence the numbers of cycles and can not be controlled. Workload and resource-usage are not stabile within multiple product development cycles.

A Decomposition-Based Approach for the Integration of Product Development and Manufacturing System Design

Yong-Suk Kim, 2002
Using a structured approach to understand the interaction between product design decisions and manufacturing system design is critical to reflect manufacturing system issues early in the product development process. Early consideration of manufacturing system issues prevents product design iterations due to manufacturing system constraints or unnecessary manufacturing system design modification to accommodate new product designs. However, in academia and industry, few frameworks

are available to capture the interaction between manufacturing system design and product design decisions.

This thesis presents an approach to capture the interaction between manufacturing system design and product design decisions, which is called manufacturability evaluation process. The manufacturability evaluation process aims to guide product development teams to see the effects of their design decisions on manufacturing systems and thus, to make the right decision from the early stage of product development. The manufacturability evaluation process satisfies four objectives: 1) to describe the objectives of manufacturing systems clearly separated from the means of achievement, 2) to present the impact of various design decisions on the achievement of the objectives of manufacturing systems, 3) to provide a common platform to effectively communicate the impact across the organization, and 4) to provide a framework to put existing tools together to integrate manufacturing system design and product design. The manufacturability evaluation process is based on a recently developed Manufacturing System Design Decomposition (MSDD).

This thesis describes three groups of case studies to identify industry practices and provide application examples of the proposed manufacturability evaluation process. The manufacturability evaluation process has been successfully applied to the cases. In addition, the interaction between manufacturing system design and product design decisions are discussed with industry case study examples in the automotive industry. An evaluation tool is developed to evaluate the general practices of a company ensuring the manufacturability of product designs. Furthermore, this thesis provides a basis for future research to extend the scope of the MSDD into product development areas.

A Framework for Achieving Lifecycle Value in Product Development
Alexis Stanke, 2001
Best lifecycle value is a concept rooted in value analysis, lifecycle consideration, and systems engineering which has evolved to support a holistic perspective of system development and program management. This thesis determines factors enabling consideration and achievement of lifecycle value by examining product development work. The scope of this effort focuses on aerospace programs to characterize lifecycle value for complex systems. Although different systems may define lifecycle value differently, there are common elements of the concept that have been identified. Based on four in-depth case studies and existing models, a theoretical framework for lifecycle value creation has been developed. The structure for this framework consists of three somewhat sequential and iterative processes: value identification, value proposition, and value delivery. Results from the case studies reported in the form of best practices have been related to this theoretical framework in six categories of value attributes. These attributes (holistic perspective, organizational factors, requirements and metrics, tools and methods, enterprise relationships, and leadership and management) apply to the entire lifecycle value framework. The combination of the framework and the practices from the case studies form a lifecycle value creation model, suggesting a lifecycle value approach encompasses appropriate and successful strategies for product development, system design, and program management.

Managing Subsystem Commonality
Matthew R. Nuffort, 2001

Common systems satisfy the requirements of multiple platforms and meet designated architecture, performance, life cycle cost, and interface standards. Commercial industry has leveraged commonality strategies, such as modular and platform-based design, to reduce product development times and costs. This research seeks to understand whether similar strategies can apply to the defense aerospace industry. The work (1) explores the benefits and costs of increased subsystem commonality in the aerospace industry, (2) addresses when it is appropriate, and (3) examines the organizational structures necessary to achieve greater commonality. The analysis draws on eight case studies of both commercial and military aerospace organizations to address the three primary research topics from a total life cycle perspective.

While quantitative data on the benefits and costs of commonality in the defense aerospace industry is difficult to obtain, the case studies suggest that commonality can significantly reduce subsystem ownership costs by reducing both the cost of acquisition and the cost of operations and support. Subsystem commonality also increases mission effectiveness by reducing cycle time, improving reliability and availability, and guarding against diminishing manufacturing sources. The work indicates that commonality in the aerospace industry generally makes the most sense at the subsystem level, where different requirements are easier to reconcile and the strategy can have a significant impact on the logistics and supply systems. A common organization that manages across platforms, such as a product center of excellence, appears to offer the greatest potential advantage from commonality.

The research reinforces the notion that strategies focusing only on the benefits of commonality in the acquisition phase of the life cycle are missing a significant portion of the holistic advantages of commonality from a system-level perspective. Platforms that deploy together and share common subsystems will likely have dramatically lower operations and support costs than platforms that might be common on the manufacturing floor but not in the field.

Design Methods in the Aerospace Industry: Looking for Evidence of Set-Based Practices
Joshua I. Bernstien, 1998

A new paradigm in engineering design, known as set-based concurrent engineering (SBCE), has been proposed which seems to offer advantages over more traditional techniques. This research, therefore, had three goals: 1) to develop a clear understanding of the definition of SBCE and to contrast that definition with other theories, 2) to assess the "set-basedness" of the aerospace industry, and 3) based on the assessment, to propose a model for implementing SBCE within an aerospace development project. While set-based concurrent engineering consists of a wide variety of design techniques, the basic notions can be stated in two principles: 1) engineers should consider a large number of design alternatives, i.e., sets of designs, which are gradually narrowed to a final design, and 2) in a multidisciplinary environment, engineering specialists should independently review a design from their own perspectives, generate sets of possible solutions, and then look for regions of overlap between those sets to develop an integrated final solution. This research found that while no company's design process completely fulfilled both of these criteria, many set-based techniques are used within the aerospace industry. Building on some of the observed industry practices, a design process model is proposed which combines concepts from lean manufacturing, such as "flow" and "pull," to implement set-based concurrent engineering.

Reducing DoD Product Development Time: The Role of the Schedule Development Process
Ross McNutt, 1998

According to the Packard Commission, "Unreasonably long acquisition cycles -- ten to fifteen years for major weapon systems is a central problem from which most other acquisition problems stem." Since the commission issued its report in 1986, the time required to develop new military systems has only grown. This research and its recommendations are intended to identify and eliminate the causes of those long development times for military systems. This report addresses a key factor in determining the development time for military projects: the project's initial schedule. Part 1 outlines the current situation, previous efforts to reduce development time, and experiences with cutting development time in the commercial sector. It also documents the military product development process. Part 2 identifies a key area--the schedule development process, and its impact on development time--for in-depth research. Through understanding what is driving the initial project schedule and the impact of the initial project schedule on the eventual development time, the author identifies key drivers of development time. Part 3 presents the results of three surveys and analyzes the processes used to develop a project's initial schedule, the process used to develop a contracted schedule, and the impact of these schedules on actual development time. Part 4 presents observations, draws conclusions, and makes specific recommendations for remedial action.

The key barriers to reducing development time for military systems are the lack of importance placed on project schedules; the lack of effective schedule-based information and tools; the lack of schedule-based incentives; and the overriding impact of the funding-based limitations on defense projects. The steps necessary to establish a focus on reducing development time are: 1) recognizing the impact of development time, 2) providing the necessary information for decision makers, 3) providing proper incentives at each organizational level, and finally providing a structure to effectively manage the set of all development projects to ensure that each project can be funded based on its development related requirements.

Implementing the recommendations and focusing on reducing development time will force other changes in the acquisition process. The focus on reducing the time to develop and field systems will drive the acquisition system to better meet the needs of our warfighters, more rapidly, and at lower cost. Better, Faster, and Cheaper. Even more importantly, shortening development times is critical to develop and produce with limited resources, the right weapons at the right time to deter or to defeat any potential enemy at any time with the minimum cost to our warfighters.

MANAGEMENT & SUPPORT PROCESSES

Risk Management

Analysis of Key Characteristic Methods and Enablers Used in Variation Risk Management
Ertan Basak, 1998
Many engineering organizations, including aerospace companies, are using Key Characteristics (KCs) to manage the risk of variation in complex products during design through manufacturing. Effective KC implementation improves the quality of the product, reduces manufacturing variation, and reduces cost of design and manufacturing. The KC Maturity Model, which identifies twenty-two supporting practices for achieving optimal KC implementation, can be used by both high and low volume companies as a self-assessment tool. This assessment can identify strengths and weaknesses in KC Practices.

Through a series of benchmark studies, it was identified that high and low volume companies have different levels of implementation success. High and low volume KC implementation is examined using company assessments. The findings about implementation successes and deficiencies are coupled into support, identification, assessment, and mitigation practices. The importance of cross-functional teams for KC implementation is another significant finding which evolved through the research.

Decision Analysis

Utilization of Dependency Structure Matrix Analysis to Assess Implementation of NASA's Complex Technical Projects
Timothy J. Brady, 2002

The National Aeronautics and Space Administration (NASA) has built a great history for achieving remarkable success in accomplishing complex technical tasks. During the 1970's and 1980's, planetary spacecraft were sent throughout our solar system which provided close-up views of the planets. However, the 1990's arrived with some project failures including a flaw in the Hubble Space Telescope's primary mirror, and the loss of three spacecraft sent to Mars.

Following the determination of the cause for the 1999 loss of Mars Climate Orbiter, the mishap investigation board reviewed eight previous failure investigation reports and identified a correlation between other project failures and a few common themes. The most common themes included inadequate project reviews, poor risk management, insufficient testing, and inadequate communications.

Most project managers are aware of the possibilities of and the consequences of these risk areas in complex technical projects – so why do many projects make these same mistakes?

This thesis developed a framework for evaluating the long-term effect of early project implementation decisions. Early decisions, such as establishing a system architecture and selecting technology of particular maturity, can have lasting impact throughout the project development process and during the project's operation phase. A systems engineering analysis framework using two different extensions of dependency structure matrix (DSM) analysis was developed to provide a comprehensive system view of the project architecture and the technology choices. An "interface DSM" mapped the dependence of components on one another and identified the impact of component criticality on the mission operations.

A "technology risk DSM" included a component technology risk factor to help identify the patterns of system level risk. The ultimate goal of this thesis was to develop an analytical framework that could be used, along with other sound system engineering tools, to expand the management team's holistic view of the project, which could then be used to enhance project implementation decision-making. The analytical framework developed in this thesis was applied to seven spacecraft projects which served as case studies. Successful and unsuccessful projects were included in the set of cases. Analytical observations were compared to post-project lessons learned to develop a general understanding of the relationship between the project structure and the implementation approach for each case.

Strategic Technology Investment Decisions in Research & Development
David I. Lackner, 1999

NASA (National Aeronautics and Space Administration) is succumbing to pressures to operate more like a private entity than a government agency; however, modern business practices are rare in the organizational structure. NASA can install project evaluation and selection techniques like real options analysis to improve capital budgeting for technology projects.

This thesis evaluates the current NASA best practices in place for technology investment decisions; evaluates the application of Real Options to the technology selection policy; and makes recommendations for the strategic management of the NASA portfolio and publicly funded R&D in general.

The key insight is that a decision process can be established to fill the current vacuum and improve budget allocation, but that real options has two weaknesses that are particularly pronounced when applied to this sector. The first is the reliance on expert opinions for probabilities. The second is the necessity to place an absolute monetary value on outcomes.

The difficulties are exacerbated by several factors: extremely long duration programs undermine estimates of expected benefits and R&D benefits are particularly intangible. Thus, for NASA, the Real Options tool is recommended considering the improvement over the current technology investment system. However, further work is required in tailoring the application to NASA's special case, and therefore the general case of publicly funded R&D. A relevant improvement would require a rigorous method of obtaining consistent probabilities and technology valuations.

Insights developed over the course of this study lead to a broader conclusion about the interaction of research & development with product development. Strengthening this connection with a tool such as real options will benefit the development activities by facilitating better capital budgeting decisions on focused technology solutions that are integrated into superior products.

A Technology Development and Business Strategy: A Changing Environment Impacts Practices.
Samuel P. Garbo, 1997
Many high technology US manufacturing industries, and especially the aerospace industry are facing unparalleled world-wide competition in a new, faster-paced, cost-conscious, global marketplace. The process of new technology development, and its earliest introduction into product production programs, is undergoing major changes in almost all US firms as they restructure for this new global business

environment. These forces of change were studied relative to their impact on how technology planning is accomplished and its interaction with company business plans. Manufacturing industries were selected and historically reviewed. An industry background was created to list major business and strategy trends known to be occurring. Independently, selective industry interviews were performed to collect complementary data on current practices and changes ongoing. A literature survey was performed to summarize major academic theories regarding planning for needed technology development, and its required interaction with firm strategic (business) planning. Results were assessed relative to the adequacy of current practices to the business environment of the mid-1990's, and the changing role of technology in industry strategy.

The Role of Product Development Metrics for Making Design Decisions in the Defense Aerospace Industry
Todd M. Scout, 1996
In current product development activities, many companies are unable to accurately predict the success of their efforts. This leads companies into dead-end development paths and often results in output that meets the contracted requirements for the program but fails to satisfy either the internal or external customers' needs. These problems arise primarily from one or more of three common problems during the development: failure to focus on the proper metrics and measurements of current activities; failure to maintain a significant historical database to facilitate corporate learning; and the use of a decision-making process that often lacks the information necessary to make good decisions.

This thesis identifies these problems through three case studies of product modifications and upgrade development programs in the defense aircraft industry. From these cases and existing literature, examples of both good and poor practices are presented to support the basic conclusions.

Causal Analysis

Characterization of Operator-Reported Discrepancies in Unmanned On-Orbit Space Systems
David Ferris, 2001

The purpose of this research is to characterize the number and type of problems satellite operators encounter during the course of routine daily activities. In the context of this paper, a discrepancy is defined as the perception by an operator that some portion of the space system has failed to operate as designed. Discrepancies can therefore include ground system malfunctions, procedural errors, and even misdiagnosis that a problem exists, in addition to actual spacecraft anomalies. The study is designed to test the following hypotheses using a verifiable, quantitative analysis: 1) the majority of problems encountered by an operator do not involve the spacecraft at all, but are attributed to other elements of the space system; and 2) correlations exist between aspects of a space system design and the nature of problems experienced by the operations staff over the long term.

To perform an applied, rather than theoretical, analysis, several representative aerospace organizations provided historical discrepancy reports for satellites currently being flown. Government civilian and military organizations participated in the study, which encompassed spacecraft from several mission areas, including remote sensing, research & development, communications, and observatories. Raw discrepancy data was collected from each organization in the form of electronic databases or hand-written logs. Data conversion consisted of selecting similar fields of interest from each database; removing references to the program, organization, or spacecraft; replacing program-specific terminology with standardized nomenclature; and merging the individual databases into one data set.

Statistical analysis of the entire data set was performed to test the two hypotheses above.The results of the analysis found that 13% of all discrepancies reported are associated with subsystems on board the spacecraft, while the remaining 87% are attributed to the operations infrastructure, including ground systems, communications relays, facilities, and associated equipment. Correlations were found between certain design characteristics and the types of discrepancies reported for a given mission. In addition, software problems were the root cause in an average 48% of the discrepancies reported for each mission.

Change Management

Causes and Impacts of Class One Engineering Changes: An Exploratory Study Based on Three Defense Aircraft Acquisition Programs
Teng-Cheng Shu, 1999
Past studies on engineering changes have focused on products other than defense aerospace products, and have concentrated primarily on the design-manufacturing interface within single companies. Thus, engineering changes in the context of US defense aerospace product development - where the user community, the acquisition community, and the contractors share the responsibility for developing a product - remain largely unexplored. This research focused on three defense aircraft acquisition program case studies, referred to hereafter as Programs A, B, and C. The primary goal of these studies was to develop a better understanding of the causes and impacts of Class I engineering changes in the US defense aerospace product development context. Class I engineering changes, simply referred to as engineering changes below, are those that fundamentally modify the form, fit, and/or function of a product such that the results before and after the engineering changes are different, and are visible to all communities involved with developing the product. In addition, this research sought to identify ways in which contractors and customers may help to reduce the number of undesirable engineering changes.

For the three case-study programs, requirements definition issues, changes in user needs, the need to fix deficiencies, and technological changes were found to be the four dominant causes of engineering changes. It was also found that program characteristics determined the dominant causes in each of the programs. Engineering changes due to the four dominant causes across the three case-study programs were found to be most likely of high-impact. The scope of impact of engineering changes remained relatively constant with respect to time, and engineering changes rarely led to subsequent, unanticipated engineering changes. Thorough requirements definition facilitated by the use of integrated product teams (IPTs), prioritization on program schedule, and the use of mature technologies combined to allow Program C to make frequent engineering changes to accommodate evolving user needs and changes in technology without any program schedule delay. It was also found that had IPTs been used during the development phases of Programs A and B, the prime contractors and their suppliers might have been able to avoid some engineering changes.

Organization Innovation and Deployment

Do Modern Tools Utilized in the Design and Development of Modern Aircraft Counteract the Impact of Lost Intellectual Capital within the Aerospace Industry
W. Geoffrey Andrew, 2001

Prior research has suggested that intellectual capital within the Aerospace Industry has been in decline. The new design aircraft experience base of Post WWIV Aerospace Engineers was approximately 6-12 new design aircraft per career. In contrast, an aerospace engineer starting his career today may experience only one, maybe two new aircraft designs during their career. Anecdotal evidence has been published linking this trend to problems experienced in many recent aircraft programs. Counter arguments cite rapid advances in design, manufacturing and information technologies used in the design and development process of today's new design aircraft have compensated for some or all of declining experience base. This thesis focuses on exploring the validity of this counter argument.

Program performance metrics were established and utilized to draw comparisons between programs. In addition, extensive interviews with personnel who played roles in these programs were conducted to that the root cause in areas of differing performance were understood.

Analysis of the data gathered revealed that the predecessor programs outperformed the more recent programs. Recommendations regarding ways to mitigate intellectual capital performance gap are presented.

Organization Environment for Integration

Transforming A New Product Development Organization: A Systems Engineering Deployment Case Study

Chandra Kay Stich Wozniak, 2002

This thesis studies the deployment of a systems engineering balanced product development organization in two new product development case studies. The study involved the development of a tool to evaluate the systems engineering process maturity achieved within the two organizations and an organizational driver analysis using a strategic, political and cultural framework. These evaluations provided data for comparing the level of maturity and functionality the two organizations had achieved as their development efforts unfolded. Additionally the organizational driver data provided a holistic perspective from which the author could make observations on how the development efforts were influenced by the systems engineering deployment. Several observations were high-lighted as having a significant influence on the amount of value the systems organizations were able to provide the new product development teams. Additionally recommendations were made on how the organizations can use these findings to reach higher levels of systems engineering capability. The list below includes the most significant observations:

- Despite dramatically different product outcomes the two teams achieved approximately the same level of systems engineering process maturity.
- Both NPD teams had limited visibility and or understanding of systems engineering as a discipline.
- Both NPD teams were not fundamentally enabled with prescriptive processes and lack knowledge or exposure to the world of process maturity and process improvement.
- The perceived success of the systems engineering organization was strongly influenced by the difference in program drivers in commercial and military product development environments.
- Both NPD teams were focused on accomplishing the tasks of systems engineering and did not leverage / engage a holistic view of systems engineering on the projects.
- The system teams provided the tasks of systems engineering that directly support product development with the most attention and critical support mechanisms of systems engineering were either overlooked or neglected by the teams.
- The system engineering organizational structure deployed in the NPD organizations creates a check and balance arrangement between program drivers and technical accomplishment.
- The immaturity of the systems engineering organization makes it highly sensitive to political and cultural influences.

These observations influence the amount of value new product development teams are able to extract from the systems engineering structure. Additionally, they illuminate the challenges faced by mature organizations as they attempt to adopt an organizational systems perspective and transform their new product development operations.

Organizational Characteristics for Successful Product Line Engineering

Michelle T. Beckert, 2000

The evaluation of strategic, political, and cultural characteristics at four organizations implementing product line engineering (PLE) was conducted. The objective was to identify non-technical characteristics that attribute to successful product line engineering efforts. A set of questions structured around defined strategic, political, and cultural characteristics was generated for formal evaluation of each organization, and then a series of interviews within each organization was performed to gather case study data.

Two of the four organizations studied were identified as being more successful with product line engineering, and, thus, were used as the basis for comparison. A comparative analysis of the organizations was performed to observe noteworthy characteristics that attributed to success. Some of the key observations include:

- Strategic plans clearly defined goals relating to the development of product lines
- Metrics were used that applied specifically to product line engineering

- PLE strategies were implemented uniformly across the organization
- The smallest percent of projects for each organization utilized the new design strategy
- Organizing resources around platforms, using modular system architectures, and implementing initiatives to standardize components facilitated resource and technology sharing
- By defining and enforcing product line strategies, senior management enabled successful product line engineering In summary, the study indicated that an organization needs strategic characteristics in place to serve as the foundation from which to implement product line engineering.

Senior management (i.e., a political characteristic) is an extension of the foundation largely because it defines the embodied strategy and enforces it. It is imperative for senior management to provide the power and resources that will enable a product line engineering culture – it is the primary link from strategy to culture. The cultural characteristics are the means by which strategies and goals are implemented and product development is executed. A PLE culture will not succeed if a strategic foundation and a political constituent do not fundamentally uphold it.

PROJECT/ENGINEERING MANAGEMENT PROCESSES

Project Planning

Improving the Management of System Development to Produce More Affordable Military Avionics Systems

Jeremy P. Tondreault, 2003

This thesis aims to improve the management of system development to deliver more affordable systems. Improving affordability is investigated from the avionics supplier's perspective. An affordable system is defined as meeting customer needs for performance and lifecycle cost in an over-constrained program space where initial development budget, schedule, performance and lifecycle cost goals are not all achievable. In certain segments of the military avionics market, the nature of competition is changing from performance to affordability based. Firms that develop competitive advantage in delivering affordable systems can capture market share.

This research is different than most literature published on affordability because it focuses on design innovation as opposed to product development and manufacturing efficiency through Lean, Six-Sigma or other techniques. Lean and Six-Sigma are necessary to improve system affordability but not sufficient to develop competitive advantage because they can be implemented by anyone on any system concept. Competitive advantage requires benefits from Lean and Six-Sigma and design innovations focused on affordability. Step function type improvements can be realized through system architecture and module design innovations that strike a better balance between lifecycle cost and performance.

Four areas are investigated: the nature of development focus during each design iteration, the role of requirements, managing lifecycle cost as a design requirement and effective integration of downstream knowledge into the design.

A model for developing requirements that strikes a better balance between performance and lifecycle cost is suggested – treating lifecycle cost as a design requirement and explicitly focusing on understanding the cost-performance trade space before developing requirements. A product development model is suggested – focusing on achieving lifecycle cost goals first and using iterations to grow performance can lead to lower cost solutions. Both the requirements development and product development models require leveraging prior knowledge, technology and capability. The requirements model requires high knowledge of system cost drivers and achievable performance. The product development model requires low technical risk allowing the team to focus on affordability first without running unacceptable levels of performance risk. Methods for increasing the effective integration of downstream knowledge are also discussed.

System Dynamics Modeling for the Exploration of Manpower Project Staffing Decisions in the Context of a Multi-Project Enterprise
Karl E. Pilon, 2001

At the Sikorsky Aircraft and Xerox Corporations, project decisions may be made on a project to project basis and often neglect to account for the complex interactions that exist between projects. Often the current decision process results in a less than optimal return to the corporation. This return may be measured in terms of organizational capability or intellectual capital. Exploration of the effects of decisions with regard to the allocation of manpower in a multiple engineering project setting is required. Also, an understanding is required as to how these daily decisions effect the development of organizational capability or intellectual capital.

The authors propose to describe and model the product development processes currently in use at the Sikorsky Aircraft and Xerox Corporations. The system dynamics method has been employed extensively in the development and application of single project models. However, the application of the system dynamics method in the understanding of multi-project systems is limited. The authors developed an original multi-project model, utilizing the Vensim toolkit, which permits the exploration of manpower resource allocation decisions based on experience of current practice at the Sikorsky Aircraft and Xerox Corporations. This model was exercised to determine the effects of proactive and reactive resource allocation decisions on an organization's ability to complete projects and expand intellectual capital. This learning environment will further the understanding of management at both organizations.

Methodologies learned from the various aspects of the System Design and Management curriculum served the purpose of problem framing and provided validation that a multi-project system dynamics model would serve as a valuable decision support tool. This holistic perspective provides a basis for process improvement and the development of recommendations applicable to the Sikorsky Aircraft and Xerox Corporations.

Recommendations for policy change are categorized with respect to anticipated payback in the near-term, intermediate and long-term time horizons. Near-term recommendations relate to overtime and project prioritization. Policies regarding resource allocation at the beginning and end of projects, as well as a project cancellation policy comprise the intermediate term recommendations. Long-term recommendations include policy that emphasizes scheduling projects with a gap between and a policy that seeks portfolio balance based on intellectual capital growth as well as monetary return on investment.

Spacecraft System-Level Integration and Test Discrepancies: Characterizing Distributions and Costs
Annalisa L. Weigel, 2000

The goal of this research is to characterize the distribution and costs of spacecraft discrepancies found at the system level of integration and test, as well as understand the implications of those distributions and costs for the spacecraft enterprise as a whole. If discrepancies can be better understood, they can potentially be reduced or even eliminated. Reducing discrepancies will result in cycle time reduction and cost savings, as well as increased product quality and reliability. All of these potential outcomes are indications of successful progress toward becoming a lean organization.

Data on discrepancies at the system level of integration were gathered from spacecraft vendor databases, while interviews with key program managers and engineers provided perspective and insight into the data. Results are based on 224 spacecraft representing at least 20 different programs or product lines, and encompassing 23,124 discrepancies. The spacecraft date from 1973-1999, and represent different vendors as well as a mix of commercial and government spacecraft.

Spacecraft discrepancies are analyzed in this work on the basis of ten categories: the spacecraft mission, the spacecraft subsystem where the discrepancy occurred, the date of the discrepancy occurrence, the discrepancy report open duration, the immediate action taken to fix the discrepancy (disposition), the root

cause of the discrepancy, the long-term corrective action prescribed to prevent the discrepancy from happening again on future spacecraft, the labor time spent on the discrepancy, and the cycle time lost due to the discrepancy. Statistical measures of central tendency, correlation and normality are presented for each category. This statistical analysis forms the basis for research findings at the enterprise level in the areas of quality yield, resource utilization, stakeholder satisfaction and flow time. Recommendations to enterprise stakeholders for increasing the value derived from system level integration and test follow from the enterprise-level findings.

Modeling and Analyzing Cost, Schedule, and Performance in Complex System Product Development

Tyson R. Browning, 1998

In the future, it is unlikely that complex system products will compete solely on the basis of technical performance. What will differentiate such systems and their developers is the ability to balance all the dimensions of product performance, including product pricing and timing (which are functions inclusive of development cost and cycle time). Furthermore, this balance must be congruent with customers' perceptions of value. Once this value is ascertained or approximated, complex system developers will require the capability to adjust the design process to meet these expectations. The required amount and sophistication of project planning, control, information, and flexibility is unprecedented. The primary goal of this work is a method to help managers integrate process and design information in a way that supports making decisions that yield products congruent with customer desires and strategic business goals.

This work consists of three parts. Part one contains two exploratory studies that further understanding of complex system product development processes. One study explores process iteration and seeks to explain why some aircraft development programs do not address iteration with existing project planning and control methods. The other study examines sources of risk, classifying these into six categories (cost, schedule, performance, technology, business, and market risks) and building causal frameworks to represent their relationships. Both studies point to avenues for improving existing process models and in some cases reveal process characteristics requiring new methods. These results, while derived from projects in the aerospace industry, are highly applicable across a variety of complex system development projects.

Part two entails an effort to model some of the characteristics observed in part one. After a review of four types of *dependency structure matrices* (DSMs), notably the activity-based or schedule DSM, extensive data are collected from an uninhabited aerial vehicle (UAV) design process. Part two thus describes how to build a DSM model and provides data for example applications of the detailed models developed in part three.

Based on the foundational work of parts one and two, part three develops a new methodology and models for understanding product development process cost, schedule, and performance. The methodology complements activity-centric schedule models such as DSM in that activities provide direct contributions to process cost and schedule and design performance.

This approach sets the stage for integrated cost, schedule, and performance analyses. A cost and schedule model is presented first, and it is extended to account for the effects of activities on product performance. The stochastic, simulation model generates distributions of possible cost, schedule, and performance outcomes. These distributions represent uncertainty and are analyzed in relation to impact functions and targets to determine levels of risk. The model outputs enable the exploration of the costs and benefits of several management options and yield interesting insights. The goal is to improve product development planning and control though the capability to balance cost, schedule, and performance appropriately.

Integrated Product Teams

Challenges and Benefits to the Implementation of Integrated Product Teams on Large Military Procurements.

Christopher M. Hernandez, 1996
Tens of millions of dollars will be spent by the United States Air Force and Navy over the next several years on the development and production of our country's top military weapon systems. The most senior leadership of these government agencies have committed their organizations to proceed with this development using a concept of management known as Integrated Product Development (IPD) using Integrated Product Teams (IPT). Essentially, the majority of the US aerospace community is moving towards this new concept of management. Since this concept comes from the commercial industry, the underlying factors of the way commercial industry does business versus aerospace, need to be explored to ensure that a model of IPD/IPT is developed which is optimized for the US aerospace industry. This thesis looks at this issue for four ongoing major aircraft developments: B-2 Bomber, C-17 Transport, F/A-18 E/F Fighter, and F-22 Fighter. These four programs are reviewed and contrasted to commercial business practices to bring out structural differences that may act as barriers to IPT Implementation. Several areas were identified that impede its implementation. These areas include: training, team budget control, and the need for balance between teams and functions. In addition, details of how benefits can be derived from the IPT concept are discussed. Current methods being used to measure these benefits are presented.

Systematic IPT Integration in Lean Development Programs.
Tyson R. Browning, 1996
Integrated Product Development (IPD) is a crucial aspect of the lean paradigm. The drive towards IPD includes an impetus to organize around Integrated Product Teams (IPTs). The use of IPTs has brought with it many issues, including those at the IPT interfaces. Program integration (of a cross-functional, upstream/downstream nature) can exist at three levels: (1) within the IPTs, (2) between the IPTs in system level teams, and (3) between the IPTs and system level teams in the program at large. This work focuses on the second and third levels, the realm of IPT interdependence, and categorizes several Integrative Mechanisms (IMs) to facilitate interteam integration. IMs are strategies and tools for effectively coordinating actions across teams within a program. To provide a variety of contexts for investigation in the defense aircraft industry, the thesis includes five case studies of development programs of varying size from each of several sectors. Each is analyzed for its use of IMs. To give a systematic basis for designing the design process, the application of the Design Structure Matrix (DSM) to model program organization based on information flow is considered in one case. DSM-based approaches to interface management have been used in the automotive and other industries. They can help a systems engineer/manager systematize the interface management process, both at a product level and at an interteam level. This facilitates decisions as to the correct utilization of IMs. These studies provide the basis for lean principles of program integration, which include designing a program for integration.

Inter-group Coordination

Multidisciplinary Design Problem Solving on Product Development
Joshua Bernstien, 2001

This investigation, conducted under the auspices of the Lean Aerospace Initiative (LAI), studied how engineers from different specialties interpret and communicate about technical design problems while working on product development teams. Data was collected on 98 cases via interviews with engineers at LAI member companies. For approximately one-third of the cases, two engineers with different backgrounds were interviewed, allowing comparisons to be made between their descriptions of the problems under study. For the remaining cases, one interview was conducted per case. The most important finding of this study was that engineers from different specialties do interpret the same problem differently. Specifically, two engineers were likely to evaluate the benefits or drawbacks of a potential solution using different sets of criteria. Thus, some design disputes were the result not of mutually exclusive needs but of a failure to recognize the different ways in which engineers were evaluating solutions to the problem. Furthermore, data collected during this study illustrated that in some cases these differences were the result of engineers addressing related, but unique problems. Therefore, a solution to one engineer's problem often created a new problem for another engineer on the team.

A second conclusion of this study was that how design tools were used had a greater impact on a team's problem solving abilities than what tool was used. In this context, design tools included objects such as

real or "virtual" prototypes as well as processes like simulations and tests. The results of this investigation suggested that such tools offered their greatest benefits when they were used in a participatory fashion in which a large fraction of a team shared in their use. Additionally, the more elements of a problem's context that were captured in a design tool, the greater its utility. Under such conditions, team members were able to create a shared evaluation system to judge potential solutions to the problem they were confronting, thereby facilitating problem resolution.

Based on these results, the traditional model of engineering communication derived from the information processing framework requires modification. The information processing model assumes that individuals have a shared understanding of meaning when they communicate. This study, however, suggests that such shared understandings do not exist in advance, but are instead created as part of the communication process. While the information processing model may work well to explain communication patterns at a high level or within a well-established group, a model that accounts for the active and dynamic creation of shared meaning is more appropriate at a detailed level.

Supplier Management

Supplier Management Practices of the Joint Direct Attack Munition Program.
Malee V. Lucas, 1996
US defense aerospace contractors have been in the process of reducing the supplier base and delegating greater responsibilities to key suppliers in order to remain competitive in the face of defense cutbacks. The trend towards greater outsourcing has meant that new products and modifications of existing systems are being designed, developed, and produced by first tier and lower tier suppliers. Supplier management becomes increasingly important as suppliers take on a greater role in product development. The Joint Direct Attack Munition (JDAM) program reveals changes in the model for supplier relationships in the defense aerospace industry that have been accompanied by unprecedented results. The joint Air Force and Navy program was designated a Defense Acquisition Pilot Program by the Department of Defense to implement acquisition reform -- particularly the reform measures of the Federal Acquisition Streamlining Act of 1994. Changes in decision-making, program structure, and organizational culture occurred as the result of reform measures and the product development administration of the program. The changes implemented by the Government as well as the innovative supplier management practices of the prime contractor showed progress in the general model for supplier relationships towards a more collaborative, team-oriented partnership. The JDAM program not only reveals the use of a new model for supplier relationships and management but also reveals that the underlying corporate strategies of subcontractor firms influenced the types of information exchanged within the program. Limitations in certain types of information exchanged, however, did not necessarily limit subcontractor contributions to product development and to program affordability goals. It was also revealed that the dynamics behind JDAM team formation influenced the type of innovation in development of the Guidance Control Unit. The linkages of the suppliers and the supplier designs resulted in innovations that changed the system architecture. In future programs, the Government, prime contractors, and suppliers may be able to manage the types of resulting designs and innovations by focusing on team dynamics and inter-relationships.

SYSTEMS ACQUISITION PROCESSES

Acquisition Practices

Product Development Strategies in Evolutionary Acquisition
Bobak Ferdowsi, 2003

Programs are consistently faced with the decision on how to best deliver capabilities to the user. This challenge is magnified by the number of uncertainties and risks the program can expect throughout the product development process—that is the means by which the program gets from perceived need to deliverable solution. The Air Force, as a result of increasing development times for new products, has

decided to implement an Evolutionary Acquisition strategy, meaning the development process focuses on delivering incremental capabilities through short increments or spirals.

The question, however, is whether this strategy makes sense across the broad spectrum of Air Force programs. More importantly, how can the Air Force, and aerospace programs in general, decide what product development strategy applies to each program? An extensive literature review yielded a number of relevant questions regarding product development. The hypothesis of this research is that this selection should be based on attributes of the product, the program goals, the uncertainties, and stakeholder involvement.

A number of case studies were performed specifically targeting programs identified as evolutionary. Analysis of these case studies showed that there was a disparity among these programs as to what was meant by Evolutionary Acquisition. These programs were shown to have a mix of strategies, but primarily followed a pattern of creating upgrades to a baseline or platform. From the case studies a number of key recommendations were made for program managers and policy makers implementing Evolutionary Acquisition, as well as a notional illustration of product development selection. Specifically, the research found that programs with high user requirements uncertainty tended towards more iteration, while programs with significant technical and performance goals had less iteration and greater planning. In programs where rapid delivery was the goal and uncertainties were relatively low, incremental strategies were found to be most applicable.

Recommendations included implementing open architecture systems through owning system interfaces, managing stakeholder expectations through system representations and internal change agents, and providing stable funding and contingency funds for rapid change implementation. Additional recommendations were made on implementing testing and logistics in highly iterative programs.

Architecting Evolutionary Strategies Using Spiral Development for Space Based Radar

Christopher James Roberts, 2003

The Department of Defense has identified the Space Based Radar (SBR) Program as a candidate for Evolutionary Acquisition to be implemented by the Spiral Development process. However, Spiral Development was originally developed in the software industry, and a consensus has not emerged about its applicability to space systems. In addition, space systems typically have not been developed with explicit considerations of architectural modularity and scalability, features necessary to enable evolutionary acquisition strategies.

A stakeholder based system architecting process known as Multi-Attribute Tradespace Exploration (MATE) provides a framework for combining computer based modeling and simulation of complex engineering systems with decision theory. The MATE process has been successfully applied to several space system projects, yielding illustrative trades analysis along the dimensions of utility and cost. However, no previous attempt has been made to incorporate the schedule dimension, a step that is critical for architecting evolutionary strategies.

Qualitative comparisons between software systems and SBR in the context of spiral development suggest a fundamental difference in system evolution and risk mitigation strategies, yet found the Spiral Development and Evolutionary Acquisition framework to be suitable to SBR. A quantitative MATE SBR software model enabled an analysis of architectural modularity and scalability, successfully incorporated the addition of the schedule dimension, and demonstrated the concept of acquisition tradespace exploration.

These analyses led to insights regarding the objectives, challenges, and limitations of applying computer based modeling and simulation as a tool for Spiral Development of evolutionary complex engineering systems.

Finally, policy recommendations for improving cost accounting, key stakeholder participation, and evolutionary options analysis were made based on findings of the research.

Make-Buy Decisions in the U.S. Aircraft Industry

Robert K. Perrons, 1997

The U.S. aircraft industry is going through a process of rapid and fundamental transformation on many levels. Drastic changes in both the level and composition of customer demand for commercial as well as military aircraft, a frenzy of consolidations in the industry, the emergence of lean manufacturing, and the "globalization" of supplier networks are making the aerospace sector very different from what it used to be. But the new realities of the industry go further than merely redefining the role of the independent aircraft company in its changing environment; they are also reshaping the very boundaries of each firm in the aircraft sector. It is therefore crucial for managers in the industry to understand one of the principal mechanisms by which a company controls the scope of its in-house activities: make-buy decisions.

This thesis approaches the topic of make-buy decisions in the U.S. aircraft industry in four ways. One, it offers insight into the circumstances and criteria behind make-buy decisions in the industry by examining two case studies involving commercial and defense products, respectively. The case studies focus as well on the vertical relationships among the companies examined, and how these relationships are realigned as a result of the prime's make-buy decisions. Two, this thesis proposes a framework that explains ex post how managers in the industry decide to make or buy a particular component or process, and that provides guidelines for approaching future make-buy decisions. The framework concentrates on two major factors that play key roles in the aircraft sector's make-buy judgments: the degree of technological maturity of the component or process, and the relative competitive market position of a firm with respect to the particular technology underlying the component or process. Three, this thesis recommends a make and buy strategy that large companies in the industry should consider for securing and maintaining a leading role in their respective core competencies. Four, it addresses the principal ways in which the aircraft industry's make-buy decisions may be affected by or may eventually lead to changes in the policies of the U.S. government.

A Study of the Federal Government's Experiences with Commercial.

Michael Anderson, 1997

The continual decline in our country's defense budget has severely impacted both government and the defense industry. To cope, the government has increasingly relied on the use of commercial procurement practices, a central tenet of federal acquisition reform. This thesis examines the impact of new commercial procurement practices from the perspective of the average defense acquisition manager. Using research information gathered from 23 current defense acquisition programs which used commercial procurement practices successfully, the thesis identifies specific practices in use, documents lessons learned from practice implementation, and investigates five core hypotheses regarding the direct impact of the practices on acquisition costs, schedule, quality, life cycle support, and life cycle costs.

From a vast array of possible business practices, thesis research identified eight specific practices that are permitted by existing policies and actively promoted within the government. Analysis of data from 23 programs found that four practices were employed by a majority of programs surveyed. Likewise research revealed that almost half of the programs reported uncertainty with item performance as the most critical risk posed by commercial procurement practices and the challenge of cultural acceptance as the greatest obstacle to implementation. In addition, a program type analysis concluded that munitions and systems acquisition programs were the most active users of commercial procurement practices. On average, these programs used four or more specific practices per program, while in comparison aircraft programs on average used less than four practices and vessel programs averaged less than three.

After thorough analysis, the research data provided evidence to support all five thesis hypotheses. Data showed that commercial procurement practices indeed reduced program acquisition costs by 4.3% and afforded indirect savings by enabling substantial staff reductions and cost/performance decision making.

In addition to cost reductions, it was found that the practices directly achieved a 17 month average program schedule reduction. In general, the majority of acquisition managers surveyed concluded that the use of commercial procurement practices actually improves product quality, does not degrade life cycle support, and does not increase life cycle costs.

An examination of common themes in the use of commercial procurement practices concluded that five practices accounted essentially for all reported program cost and schedule reductions. In conclusion, the thesis accomplished all intended goals. The thesis provided evidence to support the five core hypotheses, therefore substantiating acquisition reform rhetoric regarding the value of commercial procurement practices. In addition, the thesis revealed valuable managerial insights into the actual benefits and risks of commercial procurement practices and offered proven strategies for implementing the practices.

A System Dynamics Analysis of the Interaction Between the U.S. Government and the Defense Aerospace Industry.
Michelle V. Bakilla, 1996

The defense aerospace industry is experiencing a dramatic decrease in product orders due to the downsizing of the U.S. military. Industry leaders have recognized a need to reduce both the cost and cycle time of defense aircraft design, development, and production while maintaining product performance, quality, and corporate profitability. As a result, several aerospace companies, the Department of Defense, and researchers at the Massachusetts Institute of Technology have formed a consortium - the Lean Aircraft Initiative (LAI). The LAI goal is to identify the path for implementation of "best" practices into the aerospace industry and the government departments with which they interact. This thesis investigates the interaction of the government and the defense aerospace industry during the military procurement cycle. This interaction is demonstrated by analyzing the defense procurement system and the industry product development process using system dynamics principles. The resulting System Dynamics model identifies and seeks to quantify the interaction between the two organizations. The model interactions are calibrated against a recent military development project and the effects of variables on project performance and investigated through sensitivity analysis.

"Critical Examination of a Complex and Critical Major Acquisition for the Department of Defense: The Advanced Medium Range Air-to-Air Missile (AMRAM).",
James F. Robbins, 1994
In 1976, a group of United States Air Force and United States Navy fighter aircraft pilots told the acquisition professionals of the Armament Development and Test Center at Eglin Air Force Base in Florida the operational requirements for a new, lightweight air-to-air missile. They dreamed that the engineers and scientists of the US aerospace community could put an entire radar system more powerful than most aircraft radar into a 7-inch diameter and that the resulting missile would let them launch multiple missiles at multiple enemy aircraft from beyond visual range. As of March 1994, the operational forces have received over 3,000 missiles that surpass all expectations in performance and reliability. This thesis is a case study of the acquisition strategy and Government organization that the Department of Defense used to acquire the AMRAAM system. The AMRAAM program is explained and analyzed from a managerial perspective from the genesis of the operational requirements until March of 1994. Positive and negative lessons learned, as well as critical programmatic issues, are described for research and development, introduction of production competition through a leader/follower technique, pre-planned product improvements to sustain system performance well beyond the year 2010, management in the joint-service environment, and multi-national participation. The thesis concludes with alternative acquisition strategies that the Air Force has for the AMRAAM program. The road to AMRAAM's success as a program was long and difficult. Current and future Department for Defense programs will be benchmarked against the AMRAAM accomplishments.

Incentives

Economic Incentives in Aerospace Weapon Systems Procurement
Stacey A. Kowap, 1998

In the last several years, policy makers have attempted to make changes in the defense acquisition system to allow for a structure that provides for the selection and budgeting of the most cost-effective weapons. Senior Department of Defense officials are attempting to shift away from regulation and oversight and towards economic incentives for the procurement of higher quality and lower cost weapon systems. This thesis provides a framework for the establishment of incentives within an aerospace weapon system program. The objective of this thesis is to provide a framework for government and contractor program managers to develop economic incentives in the future. Changing acquisition policies challenge program managers as they attempt to structure procurement contracts that meet government and company goals and objectives. The framework developed highlights the critical link between the management processes within a weapon system acquisition program and the establishment of economic incentives. Practices are described that help identify, quantify and foster the development of incentives.

The practices discussed derive from four case studies completed as part of this thesis. These case studies document how each program established their economic incentives, and show they were not simply derived from a formula used in the government's weighted guidelines (WGL) for profits, or other procurement directive or list. Each program's economic incentives are tied to risks specific to the completion of that weapon system. Programs that successfully use economic incentives capture the major risks to execution of their weapon system program and plan for methods to mitigate those risks.