Lean Aerospace Initiative Research Projects

Phase III (September 1999 – August 2002)

October 15, 2001

Contents:

Lean Enterprise Team Project

Title: Controlling the Lean Aerospace Enterprise - Development of an Intelligent Decision Aid for Enterprise Management

Motivation: The objective of this research is to develop an enterprise-level management control mechanism for the aerospace industry, based on the tenets of "Lean" practices that focus on delivering customer value. The Lean Aerospace Initiative (LAI) at MIT has developed a suite of best practices that aim to propel the U.S. Aerospace Industry into a new era of operations by increasing value and reducing product costs, production cycle time, waste, etc. Historically, much of the research has only focused on the actual production of aerospace systems, which on average accounts for only 15% of the real cost of any new aerospace system. If one takes a broader view, and looks at the entire enterprise involved in providing an aerospace product or service, there is a potential for developing significant competitive advantage through value creation and waste reduction. Research to date has identified that a shift towards a Lean Aerospace Enterprise can help in this repositioning, and the development of an enterprise-level management control mechanism for the aerospace industry could serve as a rigorous systems-based framework for directing this change.

Key Questions:

- What is a ***Lean Aerospace Enterprise***?
- How is the ***state of leanness*** of the enterprise assessed and what does it signify (what is the enterprise's comparison basis or reference state and what is the desired future state)?
- How are actionable items for ***enterprise policy and management*** chosen and prioritized based on the analysis of the state of leanness of the enterprise?

Research Design: Site visits focusing on the "Lean Enterprise Self-Assessment Tool" (LESAT) are ongoing. Literature searches and site visits have highlighted the lack of agreement on the definitions associated with a Lean Aerospace Enterprise. The first step in this research will focus on promulgating a set of definitions for the industry. Next, a theoretical model of the causal interactions and chronological ordering of LESAT practices will be developed and compared to data acquired during the LESAT beta testing. This comparison will form the basis for a systems management tool that will act as the core of an intelligent decision aid for managing a Lean Aerospace Enterprise. Further LESAT data will be collected to both increase the sample size for the model development, and potentially add a chronological data set to the experiment if the sampling time is within an acceptable limit. Ultimately, the intelligent decision aid is aimed at guiding Aerospace Enterprise Executives who perform Self-assessments and then ask "What Next?"

Staffing: Cory Hallam will be the primary research assistant for this effort. The Ph.D. committee chair is Prof. Deborah Nightingale, with Tom Allen and John Deyst as Committee members.

Timetable: This project commenced in Fall 2000 and is expected to be completed by December 2002.

Expected products: Ph.D. thesis reporting on major research findings, briefings at workshops and conferences, inputs into the lean Enterprise Model (LEM).

Product Development Team Project

Title: Valuation Techniques for Commercial Aircraft Program Design

Motivation: The commercial aircraft conceptual design phase is characterized by simultaneous tradeoffs of numerous parameters. When such parameters are easily quantifiable, such as drag, range, fuel burn, or gross weight, the design task is relatively straightforward and may be achieved through numerical or analytical optimization techniques. However, the traditional design framework becomes very difficult to apply when dealing with system-related design variables, because the appropriate tools are not well integrated or do not exist. Such variables include the product mix within a family of aircraft; the level of commonality across several aircraft types; the timing of development and production schedules; and management decisions made throughout the program based on the continuing resolution of uncertainty.

Key Questions: The questions below are representative of the goals of the research; however they may be modified as the project develops.

- What is the effect of flexibility on program value in commercial aircraft development?
- What is the optimal level of flexibility in a commercial aircraft program?
- How can flexibility be built into an aircraft design and an aircraft program?
- What is a useful systematic approach for designing an aircraft at the product level and the program level simultaneously?

Research Design: The research started with an assessment of existing tools and methodologies used in conceptual design and in addressing value to the company. This assesssment was conducted primarily using a Boeing Phantom Works design team as an example. Simultaneously, techniques are being explored for defining and computing an appopriate metric for company value. These techniques include Discounted Cash Flow analysis and extensions addressing the effect of uncertainty and flexibility on program value. Such extensions include Decision Analysis and Real Options. Finally, a quantitative model is being developed to demonstrate the dynamics of simultaneous product- and program-level aircraft design. The model is implemented in C and designed to be compatible with (but not dependent upon) one or more proprietary models used in industry for cost and performance analysis. In its final state, the model will evaluate one or more hypothetical aircraft programs based on their technical and program-level properties. This will facilitate trade studies to identify how to use product and program flexibility to capture the maximum value for the aircraft manufacturer.

Staffing: Jacob Markish (Candidate for S.M. in Aeronautics and Astronautics; supervised by Dr. Earll Murman and Dr. Karen Willcox)

Timetable: Model development starting in 2/01, achieving baseline functionality by fall 2001. Working papers and presentations periodically through 5/02, thesis by 5/02.

Expected Products: S.M. Thesis, LAI working papers, LEM data sheets, presentations.

Relationship to the Research Agenda: This research contributes to ongoing work in the area of Product Development.

Product Development Team Project

Title: Valuation Techniques for the Design of Space Systems

Motivation: The decision of whether or not to pursue a new large-scale project is crucial to the success of a company in the aerospace industry. To make this decision, many aspects of the project are considered, including both its technical and financial feasibility. Often these two issues are intertwined. For example, a project may be technologically feasible if a company is willing to spend exorbitant amounts of money on development. In this respect, the project may make technological sense but its financial viability is compromised by the development costs. In addition, once a project is initiated the optimal design path is often unclear. Traditional valuation techniques do not capture the full value of projects, nor do they shed light on an optimal design path.

Real Options is an alternate technique for project valuation, especially useful in situations with significant uncertainty. It has been applied with success in several industries, such as the pharmaceutical industry, but has seen limited use in aerospace. A real options approach captures the financial value of a project better than standard valuation methods, including net present value and discounted cash flow because it takes into account the value of managerial decisions during the life of the project. It also allows the user to identify optimal decisions during a project that will increase its financial viability.

Key Questions: The key questions include the following:

- What is the value of starting a new complex space project?
- How can this value be measured and quantified in a systematic fashion?
- How does the interaction between financial and design issues affect the viability of a project?
- How do valuation techniques force the examination of these interactions?

Research Design: The real options approach to project valuation will be used to capture the value of the Aquarius low-cost, low reliability launch vehicle concept. The research will capture some of the financial and technological trades between using a new technology that would substantially change the design of spacecraft and remaining with the standard design. A trade study will be performed to determine the value of being able to provide low-cost fuel on orbit to satellites, which will enable either cheaper launches or an increase in payload. The information gained from this trade study, along with other collected data, will then be used as inputs into the overall project valuation. The final step will be to create a general framework to evaluate both the design and financial issues associated with undertaking a novel space system project.

Staffing: Michelle McVey (Candidate for S.M. in Aeronautics and Astronautics; supervised by Dr. Joyce Warmkessel)

Timetable: Literature review and research development through 3/01 with preliminary site visits and interviews continuing through 5/01. In-depth case study of project during the summer of 2001. Continue work on case study through 12/01 and thesis by 5/02.

Expected Products: S.M. Thesis, LAI working papers, LEM data sheets, presentations.

Product Development Team Project

Title: Value Stream Analysis of Aircraft Flutter Testing and Evaluation

Motivation: The testing and evaluation (T&E) of new aircraft, or aircraft upgrades, can be a long and costly process. Over the years significant effort has been put forth to modernize test facilities -- specifically with regards to data processing and handling of test articles -- to minimize cycle time and cut down on test costs. Significant modeling and simulation capabilities have also been developed. Despite these efforts, T&E continues to be an area needing process improvements as aircraft systems become more complex, customers expect reduced costs and shorter development times, and the political consequence of failure increases.

Flutter testing was chosen as the focus of this research for a variety of reasons. It is performed on all aircraft and thus case studies can be drawn from both commercial and military aircraft. It is also a mature area with well-defined test techniques in both ground and flight testing. This provides for a relatively common framework between programs. Exploratory work has indicated there are opportunities for improving flutter T&E. Finally, flutter testing is generally not controversial or highly classified, allowing for easier access to data and willing participation by industry and government partners.

Key Questions:

- What activities make up the flutter T&E value stream and what are their durations?
- Where are the opportunities for improving the flutter flight T&E process?
- What are causes for deviations from baseline flutter flight test schedules?
- Which deviations add value and which ones represent waste?
- What T&E process improvements could be made to reduce waste or enhance value?

Research Design: To address these and related questions, case studies will be performed. Six aircraft programs will be studied: three military and three commercial. Candidate programs include the F-22, F/A-18E/F, JPATS, C-130J, 737-NG, and the Premier business jet.

The research will begin with a comparison of flight test schedules and their corresponding daily test logs to identify how well the initial schedules were adhered to. A more detailed analysis of the daily logs will follow. Attention will focus on determining the root cause of unsuccessful and unplanned tests and the impacted that they had on the test schedule. Some of these tests will be valuable, uncovering improvements needed to assure the product meets the end user's expectations. However, others could be prevented, and represent waste than can be eliminated through process improvement. The goal is to identify ways to minimize waste by improvements in the upstream T&E activities, the testing infrastructure, and/or the overall process.

Staffing: Research Assistant Carmen Carreras, supervised and assisted by Prof. Earll Murman

Timetable: Project initiated June 2001. Completion is expected June 2002.

Expected Products: Master's Thesis, reports on major research findings, briefings at workshops and conferences, and recommendations for flutter T & E process improvements.

Manufacturing Systems Team Project

Title: Design of Complex Manufacturing Systems and Verification of Manufacturing Design Framework on Assembly Operations

Motivation: The ultimate goal of this research is to develop a method to design an appropriate manufacturing system for enterprises in the aerospace industry. There are many factors that make this industry unique. We are interested in providing consortium members information on what type of manufacturing system design is possible given their manufacturing environment. Previous research has developed a framework describing the manufacturing system design environment. The purpose of the current project will be to test the framework in aerospace assembly operations and contribute to the development of the manufacturing system design guidelines.

Key Questions: The key questions this research addresses are:

- How are manufacturing systems integrated with the overall enterprise strategy?
- What are the requirements/considerations/constraints which most influence manufacturing system design?
- What are the current frameworks or methods used in the design process throughout industry?
- What are the emergent key characteristics for manufacturing system design?

Research Design: This research has three stages. The first stage, now completed, was to understand those influences that affect the design of the manufacturing system. The second stage was the development of a framework for manufacturing system design. This effort was a team effort developed through literature and team ideas. The final stage is to determine the validity of the framework and outline any emergent key characteristics. Various active manufacturing systems currently under development are being treated as case studies. The case studies are being conducted in real time, or retrospectively, across the industry. The sectors included in this research are airframe, electronic and space (satellites and launch vehicles). By studying the design methodologies in use and the comparison to the previously developed framework, we hope to develop guidelines for manufacturing system design.

Staffing: This research will be a team effort among Tim Gutowski, Stan Gershwin and Tom Shields with the assistance of graduate student Mandy Vaughn. Mandy Vaughn will apply the previously developed framework in assembly operations of the aerospace industry. Joyce Warmkessel will be the thesis advisor for Mandy Vaughn. Tom Shields will be the designated thesis reader.

Timetable: During academic year 2000-2001 the framework was developed. During academic year 2001-2002 the case studies will be conducted and reported.

Expected Products: The framework was discussed at the Manufacturing Systems Team Meeting February 2001. Verification of framework and manufacturing system design guidelines will be presented at March 2002 Plenary Conference.

Manufacturing Systems Team Project

Title: Improvement of Manufacturing System Design Through the Development of New Tools

Motivation: The goal of this research is to develop tools to aid aerospace companies in improving the success of manufacturing system design and redesign. Through the use of an in-depth job shop case study it was found that value stream mapping was beneficial in trying to organize a system redesign. Value stream mapping is a common design tool used in the industry to redesign systems and helps to bring together different expertise and creativity and allows easy identification of system goals. The purpose of the current project will be to study a cross section of those using value stream mapping in their companies and compare and contrast the success of the methods used. The conclusion of this research will be the design and testing of additional tools that can aid value stream mapping and improve the success rate of a system design.

Key Questions: The key questions this research addresses are:

- What methods and tools do organizations use to develop a future value stream from the current value stream?
- What of these methods could be used to improve the success of value stream mapping as a whole?
- What tools can be used to improve the success of the value stream mapping workshops?

Research Design: The first phase of the research began with an in-depth case study of a fabrication job shop. A redesign was done using current system design tools, and will be presented as an evaluation of these tools and methods. The case study helped to identify improvement areas within manufacturing system design. The next phase will begin with a series of site visits to companies with multiple value stream mapping experience levels. The processes used to develop future states from current states will be compared and a measure of success will be developed. Through these visits the need for addition tooling will be developed. The third phase will be the development of solutions, in the form of additional tools, which can be used to fill the current holes of value stream mapping. Possible tools include: identification of the trigger, determination of inventory levels, and guidelines for dealing with shared resources. The third phase is the testing of these tools within a value stream mapping workshop.

Staffing: Research Assistant Rhonda Salzman assisted and supervised by Tim Gutowski, Stan Gershwin and Tom Shields. Tim Gutowski will be the thesis advisor for Rhonda Salzman. Tom Shields will be the designated thesis reader.

Timetable: Completion of work by April 2002. Completion of development of tools to be presented at Plenary 2002.

Expected Products: Analysis of current procedures for value stream mapping and recommendations for use in other companies. Tools, including estimation of trigger point and inventory levels, to use in order to improve success and limit risk of value stream mapping workshops and system redesigns.

Supplier Networks Team Project

Title: Fostering Innovation Across Supplier Networks

Motivation: The supplier base accounts for much of the total cost of major defense acquisition programs, such as the F-22 Raptor. Also, a significant share of technological innovation across many industries takes place at the interface between customer companies and their suppliers. A key challenge, therefore, is how best to motivate and tap supplier-based innovations to optimize lifecycle affordability benefits. This challenge is particularly important in the area of avionics systems, which have come to assume a central role in terms of technological complexity, scope and speed of technological change, and total acquisition cost. Hence, this project concentrates on avionics systems and seeks to identify effective ways of fostering supplier-based process innovations to achieve greater program affordability in weapon systems acquisition.

Objective: The research objective is to develop a greater understanding of the most effective strategies and methods, as well as acquisition policies and practices, that can be employed to foster innovation across supplier networks in order to achieve weapon systems performance and affordability goals.

Research Questions: This research project addresses the following types of major questions:

- What are the most effective ways of incentivizing supplier-based process innovations to help reduce production costs and mitigate the problem of parts obsolescence and diminishing manufacturing sources in a fast-clockspeed technology environment?
- What are the best ways of overcoming barriers to the continuous flow of innovation benefits?
- What are innovative business models, acquisition policies and practices, and supplier integration strategies for continuously motivating and tapping supplier-based innovations to optimize lifecycle affordability benefits?

Research Design: While much of the literature on product and process innovation focuses on innovation *within* the boundaries of a given firm, this thesis examines innovation by concentrating on the interfaces *across* firms, focusing on interactions between customer firms and their supplier networks. The research concentrates on military avionics systems, focusing primarily on the F-22 Raptor. The study first traces the evolutionary development of avionics systems and related supplier integration issues. It then addresses the research questions listed above by conducting selected case studies focusing on major avionics subsystems (e.g., radar, electronic warfare, central integrated processor). These case studies involve site-visits and in-person interviews with a spectrum of key personnel associated with the design and development of these subsystems, as well as with procurement and supply chain management personnel, at both the prime level (i.e., Lockheed Martin) and at each one of the major subcontractors. Further, in-person as well as telephone interviews are conducted with representatives of a selected sample of subtier suppliers supporting these major subsystems.

Staffing: Aaron Kirtley (Candidate for the MS Degree in Mechanical Engineering *and* in Technology and Policy). Thesis Supervisor: Dr. Kirk Bozdogan; Reader: Dr. Daniel Whitney.

Timetable: This research project is expected to be completed by January 2002; the broader research activity in this general subject area is expected to be continued beyond this milestone date, with staffing and scheduling decisions to be determined.

Expected Products: This research activity is expected to result initially in a Master's thesis (January 2002), as well as working papers and publications summarizing major research findings. The research will also provide inputs to the Lean Enterprise Model (LEM), Transition-to-Lean (TTL) Roadmap, Lean Enterprise Self-Assessment Tool (LESAT) and other LAI products, including complementary products being developed by the Supplier Networks Research Team, such as the FRAMEWORK for lean supplier network capability assessment. Additional products include a self-assessment tool for gauging supplier innovation capability levels, as well as a White Paper summarizing policy recommendations.

Organizations & People Team Project

Title: Managing Change in Complex Organizational and Product Settings

Motivation: Despite numerous books describing how to manage change in organizations, large-scale system change is difficult to do successfully. The aerospace industry has been engaged in massive consolidations and restructuring during the major part of the last decade. This research seeks to first document the change initiatives that have been underway during the time frame from 1993-present. That time frame is suggested because it coincides roughly with the beginning of the Lean Aerospace Initiative and also the release of the Carnegie Commission report on defense technology that stimulated many of the later acquisition reform initiatives. From that baseline, the research will then focus on the overall patterns of success and failure in individual change initiatives, seeking to explain the factors that contribute to success. It will then look at overall systemic change effects that have resulted from the individual change initiatives, to better understand and predict success in large scale system change initiatives.

Key Questions: The key questions for this research are:

- What were the characteristics and objectives of major change initiatives that occurred within the US aerospace enterprise during the time period 1993-present?
- How many of them were successful, and by what metrics was success measured?
- What factors played a consistent role in the success cases? What factors played a consistent role in the failure cases?
- How did the individual cases of success or failure contribute to overall system-level change in the respective enterprises in the study?

Research Design: This research will perform a census of change initiatives within both industry and government during the time frame 1993-present. The unit of analysis of what constitutes a change initiative will emerge through a process grounded in empirical field investigation, coupled with relevant theory guidance. For each change initiative identified, the research will collect descriptive data on the scope, characteristics, effort or resource commitment, activities and stakeholders, and outcomes (cycle time, success/failure, etc.). It will also try to collect information attributing specific practices or attributes to the outcomes achieved. Also, the UK/LAI has placed an emphasis on studying change management. Efforts will be made to benefit from whatever synergies might exist between the efforts mentioned above and this one focused on change.

Staffing: Sandra Kassin-Deardorff (SM TPP) began work on this project in September 2000. The thesis advisor is Eric Rebentisch.

Timetable: This research will be completed in December 2002.

Expected Products: Research progress will be reported at Organization & People Team meetings as the work progresses. A thesis and other possible publications will result from the research.

Organizations & People Team Project

Title: Principles and Practices of Licensing

Motivation. The research project was spurred by recent changes in the landscape of innovation-driven firms. Importantly, as knowledge needed to produce a continuous stream of competitive products has simultaneously become more complex and more dispersed, licensing of new leading-edge technologies has emerged as a key element of competitive success in a range of industries. Yet the performance of licensing projects varies greatly within as well as across firms. This is a reflection of the lack of comprehensive knowledge about how to design and implement effective strategies and processes for licensing.

Objective and outputs. The research will identify and analyze the factors that make some licensing efforts more effective than others. Findings will be captured in the following output:

- Best practices ('know-what'). What practices set the successful projects and firms apart from the less successful ones?
- Execution ('know-how'). How do the successful projects and firms execute their practices?
- Building sustainable licensing capabilities. If executing best practice was just a matter of 'know-what' and 'know-how', performance differences would soon evaporate as best practices spread. We believe that the capability to execute best practices of licensing rests on a complex set of inter-linked factors that evolve only slowly over time. An important aim of our research is to identify these factors and come up with recommendations as to how firms may develop world-class licensing capabilities over time.

Research design. The research is conducted in two stages. The first stage, which was recently completed, entailed in-depth studies of a dozen in-licensing projects at three pharmaceutical drug development sites. This resulted in the generation of a number of testable hypotheses. The second stage, which is currently under way, entails constructing a survey instrument that tests the hypotheses generated during the first stage, which will then be distributed to team members in a large number of projects and firms, both in the pharmaceutical and the aerospace industries.

Staffing. The research is conducted by Henrik Bresman, a doctoral candidate in the organization studies group at the Sloan School of Management. Eric Rebentisch is the LAI advisor.

Time table. The project will be completed by the summer of 2003.

Organizations & People Team Project

Title: Measuring and Managing Intellectual Capital

Motivation: "Intellectual capital" has been heralded in recent business journals as an important component for successful business development. Intellectual capital (IC) consists of the people, relationships, tools, and processes that create value for the firm and its clients.

This research seeks to identify tools and methods to measure intellectual capital's contribution to organizational productivity. Considerable research to date has emphasized the financial measure of IC – for example, the valuation of intellectual property and corporate intangible assets. Others have valued IC simply as the difference between a firm's market value and book value. However, these financial measures are not useful to a manager, as they provide few insights about how to improve operations or assess the health of the organization.

The objective of the research is to develop and validate a measuring instrument that will allow organizations to measure and assess the health of their intellectual capital base. It is hoped that this would allow senior level managers to better structure the workforce for enterprise productivity.

Key Questions: The key questions for this research are:

- What are the most effective measures of intellectual capital in people, organizations, and in the important relationships with clients and the supply chain?
- What is the interaction between people, knowledge management systems, and intellectual property in the firm's knowledge base?
- How can managers assess whether their IC assets are aligned with the goals of the project?
- Can the measurement of intellectual capital assist in identifying potential areas for resource acquisition or allocation?
- Can intellectual capital aid in forming organizational strategies for productivity improvement?

Research Design: This research will use case study methodology to collect data on product development (PD) teams at various aerospace firms. The research will use the concept of IC as a "lens" for evaluating PD efforts, including the so-called "fuzzy" front-end of the PD process. The case studies will emphasize intellectual capital and its utilization in the context of each project, and its contribution to the project's success. A broad range of studies is envisioned to illustrate how different intellectual assets may be needed to achieve diverse project goals.

Staffing: Larry Siegel (SM TPP) began working on this project in January 2000. The thesis advisor is Eric Rebentisch.

Timetable: This research will be completed in January 2001.

Expected Products: Research progress will be reported at Organization & People Team meetings as the work progresses. A thesis and other possible publications will result from the

research. The thesis will include evaluation tools, currently envisioned in the form of maturity matrices, which will allow practitioners to gauge the intellectual capital in their organizations.

Joint Acquisition Team/Organizations and People Team Project

Title: Stakeholder Collaboration in Defense Acquisition

Motivation: The primary stakeholders in the acquisition of new capabilities for existing weapon systems are the end user, acquirer, and prime contractor. These stakeholders share a common legacy of command and control management, tending to place strong emphasis on a planning and measurement focus. However, stakeholders have differing and dynamic perspectives and priorities, and in defense acquisition, they face uncertainties such as a changing threat, time-varying political support and unpredictable rates of technology development. Dependence on up-front planning and fixed processes can limit adaptability. An important challenge for the Air Force is to determine how best to foster collaboration to develop and maintain shared understanding between stakeholders, and to allow for adaptive responses to uncertainty. Developing and refining a relationship focus on the part of the stakeholders through attention to stakeholder collaboration holds the potential to deliver more value, in terms of capability added within budget constraints, to the warfighter. Closely coupled with collaboration is the need for sufficient control mechanisms to ensure that fiscal and legal constraints will be enforced and program stability can be maintained. My research will assess collaborative modes and mechanisms, and associated control mechanisms, to determine those with the greatest potential to enhance value-creating decisions in varying program phases, activities, and contexts.

Key Questions: Research will address the following major questions:

- What are the beneficial collaborative activities (for each phase)?
- What collaborative roles should the stakeholders have (for each phase and activity)?
- How can collaboration and control be effectively balanced?
- What collaboration mechanisms, associated with different activities and contexts, lead to a best value decision process (lowest cost to use, highest benefit, and timely decisions)?

Research Design: This research effort will seek to provide precise insight into the primary collaborative activities and associated roles of the primary stakeholders during concept exploration, requirements definition, and design phases. Specific interactions represent opportunities to flow rapidly changing information, promote understanding and synergistic thinking between stakeholders, and construct adaptive responses to maximize value in a range of contexts. Case studies will seek to address the above research questions through contact with user, acquirer and contractor stakeholders involved in collaborative activities during acquisition of new capabilities for existing weapon systems. Benefits of the research include a framework to support making better collaborative decisions, policy recommendations and training materials.

Staffing: Lt. Col. Rob Dare will be the primary researcher. Dr. Eric Rebentisch (Organizations and People and Acquisition Teams) will serve as LAI advisor. The Ph.D. thesis committee consists of Prof. Earl Murman, Prof. Sheila Widnall, Prof. Tom Allen and Dr. Eric Rebentisch.

Timetable: Completion of the project is expected by August 2002.

Expected products: Report on major research findings, briefings at workshops and conferences, inputs into the Lean Enterprise Model (LEM), and a Ph.D. Thesis.