

## INTERNET DOCUMENT INFORMATION FORM

**A . Report Title: Best Manufacturing Practices: Report of Survey  
Conducted at Lockheed Martin Tactical Aircraft Systems, Fort Worth, TX**

**B. DATE Report Downloaded From the Internet: 12/19/01**

**C. Report's Point of Contact: (Name, Organization, Address, Office  
Symbol, & Ph #): Best Manufacturing Practices  
Center of Excellence  
College Park, MD**

**D. Currently Applicable Classification Level: Unclassified**

**E. Distribution Statement A: Approved for Public Release**

**F. The foregoing information was compiled and provided by:  
DTIC-OCA, Initials: \_\_VM\_\_ Preparation Date 12/19/01**

The foregoing information should exactly correspond to the Title, Report Number, and the Date on the accompanying report document. If there are mismatches, or other questions, contact the above OCA Representative for resolution.



REPORT OF SURVEY CONDUCTED AT

**LOCKHEED MARTIN**

**TACTICAL AIRCRAFT SYSTEMS**

**FORT WORTH, TX**

*AUGUST 1995*

## ***BEST MANUFACTURING PRACTICES***



*Center of Excellence for Best Manufacturing Practices*

**20011220 067**

ABJ 02-03-0562

# PREFACE

---



During the week of 7 August 1995, a Best Manufacturing Practices (BMP) survey was conducted at Lockheed Martin Tactical Aircraft Systems (LMTAS) located in Ft. Worth, Texas. LMTAS is a government-owned, contractor-operated facility designated as Air Force Plant 4, located adjacent to the realigned Carswell reserve base. This division of Lockheed Martin employs more than 11,900 personnel with a 1994 payroll of \$677.76 million. Facilities encompass 602 acres with over seven million square feet of building space. LMTAS supports several major programs including the Air Force's F-16 Fighting Falcon, FS-X, and F-22 Air Superiority Fighter aircraft. It also leads Lockheed Martin's effort in the

Joint Advanced Strike Technology program to develop future tactical aircraft for the Navy, Marines, and Air Force.

The BMP program surveyed this company in 1988 when it was known as the Fort Worth Division of General Dynamics. Significant practices documented then are still in evidence today at LMTAS. The proactive approach to environmental concerns provide an example of this as a program that has resulted in millions of dollars saved over the last 7 years. Combining General Dynamics with Lockheed has produced a strong company that provides its customer with the highest quality products. LMTAS has also developed and enhanced new practices and processes. LMTAS' Lean Enterprise Initiative program and a strong relationship with its suppliers have resulted in a rightsized workforce *and* a 38% cost reduction to the F-16 program. These efforts rely on highly-developed integration and communication programs as underlying support mechanisms to execute initiatives and practices. Building on past successful practices, cultivating current programs, and effectively integrating processes and product development provide LMTAS strong capabilities to ensure it remains a premier aircraft production company and critical component of the U.S. defense industrial base well into the 21st century.

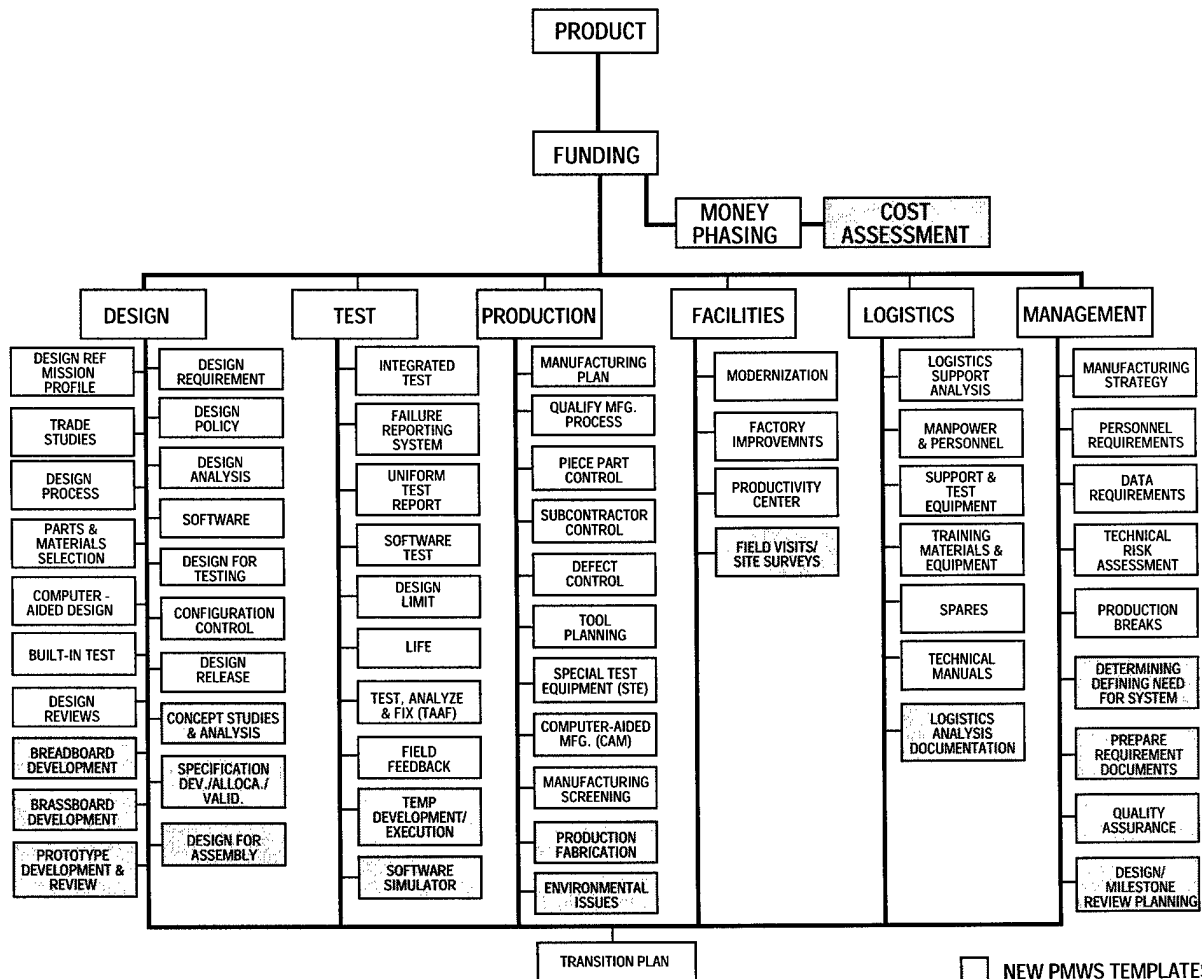
BMP surveys are conducted to identify best practices in one of the critical path templates of the Department of Defense (DOD) 4245.7-M, "Transition from Development to Production." This document provides the basis for BMP surveys that concentrate on areas of design, test, production, facilities, logistics, and management. Practices in these areas and other areas of interest are presented, discussed, reviewed, and documented by a team of government engineers who are invited by the company to evaluate the company's policies, practices, and strategies. Only non-proprietary practices selected by the company are reviewed. In addition to the company's best practices, the BMP survey team also reviews potential industry-wide problems that can be referred to one of the Navy's Manufacturing Technology Centers of Excellence. The results of the BMP surveys are entered into a database for dissemination through a central computer network. The actual exchange of detailed data is between companies at their discretion.

The Best Manufacturing Practices program is committed to strengthening the U.S. industrial base. Improving the use of existing technology, promoting the introduction of enhanced technologies, and providing a non-competitive means to address common problems are critical elements in achieving that goal. This report on Lockheed Martin Tactical Aircraft Systems will provide you with information you can use for benchmarking and is part of the national technology transfer effort to enhance the competitiveness of the U.S. industrial base.



# BMP

## “CRITICAL PATH TEMPLATES FOR TRANSITION FROM DEVELOPMENT TO PRODUCTION”



# CONTENTS

---

---

## 1. EXECUTIVE SUMMARY

1.1	BACKGROUND .....	1
1.2	BEST PRACTICES .....	2
1.3	INFORMATION .....	5
1.4	ACTIVITY POINT OF CONTACT .....	7

---

## 2. BEST PRACTICES

### 2.1 FUNDING

#### COST ASSESSMENT

Dedicated Cost Team .....	9
Risk Management .....	10

### 2.2 DESIGN

#### DESIGN REFERENCE MISSION PROFILE

Flight Control Simulation Laboratory .....	10
--	----

#### DESIGN REQUIREMENTS

Modeling and Simulation .....	11
Electrical Power System Integration .....	12

#### DESIGN POLICY

F-16 Cockpit Review Team Process .....	12
--	----

#### SOFTWARE DESIGN

Software Development Process .....	13
------------------------------------	----

#### COMPUTER-AIDED DESIGN

Conceptual Design Environment .....	13
CATIA Design Tool .....	14
Design Integration with COMOK .....	15

#### DESIGN REVIEWS

Product Proof and Prototype Validation .....	15
--	----

#### CONFIGURATION CONTROL

Root Cause Analysis .....	16
---------------------------	----

#### DESIGN RELEASE

Engineering Source Data Requirements .....	16
--	----

# CONTENTS (Continued)

---

<b>2.3</b>	<b>TEST</b>	
	<b>INTEGRATED TEST</b>	
	Avionics Systems Integration .....	17
	<b>FAILURE REPORTING SYSTEM</b>	
	Logistics Support Analysis Program .....	17
	<b>FAILURE REPORTING SYSTEM</b>	
	Aerospace Safety Program .....	18
<b>2.4</b>	<b>PRODUCTION</b>	
	<b>DEFECT CONTROL</b>	
	Shop Floor Statistical Process Control .....	18
	<b>COMPUTER-AIDED MANUFACTURING</b>	
	Fuel System Simulator .....	19
	<b>ENVIRONMENTAL ISSUES</b>	
	Hazardous Material Management .....	20
<b>2.5</b>	<b>FACILITIES</b>	
	<b>FACTORY IMPROVEMENTS</b>	
	Asset Consolidation .....	21
<b>2.6</b>	<b>MANAGEMENT</b>	
	<b>MANUFACTURING STRATEGY</b>	
	Integrated Product Development .....	21
	Lean Enterprise Initiative .....	22
	Modified Requirements Contracts .....	23
	Factory Layout Planning Techniques .....	23
	MRP II .....	24
	<b>PERSONNEL REQUIREMENTS</b>	
	Ergonomic Tooling/Manufacturing .....	24
	<b>QUALITY ASSURANCE</b>	
	Goal Deployment .....	25
	Product Definition and Design Metrics .....	26
	Internal Review Process .....	27
	Supplier Relations .....	27
	Supplier Rating System .....	29
	Supplier Statistical Process Control .....	29
	Supplier Performance Evaluation and Review Program .....	31
	F-22 Variability Reduction .....	31
	On Call and Just-In-Time .....	31
	Continuous Performance Improvement .....	32

# CONTENTS (Continued)

---

## 2.6 MANAGEMENT (CONTINUED)

### DESIGN/MILESTONE REVIEW PLANNING

Supplier Integrated Product Development ..... 33

### MAKE OR BUY DECISIONS

Outsourcing of Non-Core Processes ..... 33

---

## 3. INFORMATION

### 3.1 FUNDING

#### MONEY PHASING

MRP Purchasing Management System ..... 35

Automated Budget Control System ..... 35

### 3.2 DESIGN

#### DESIGN POLICY

Process Quality Policies ..... 35

#### DESIGN ANALYSIS

Design Cost Integration ..... 36

#### PROTOTYPE DEVELOPMENT AND REVIEW

Product Modeling and Simulation ..... 36

### 3.3 PRODUCTION

#### DEFECT CONTROL

Variability Reduction ..... 37

### 3.4 FACILITIES

#### MODERNIZATION

Process Development Center ..... 37

### 3.5 LOGISTICS

#### TRAINING MATERIALS

Research and Engineering Learning Resource Center ..... 37

### 3.6 MANAGEMENT

#### MANUFACTURING STRATEGY

Flight Control Systems Teaming ..... 38

Commercialization ..... 38

# CONTENTS (Continued)

---

## **MANUFACTURING STRATEGY (Continued)**

Product Definition and Design Business System .....	39
Quick Reaction Procurement .....	40
Electronic Procurement Process .....	40
Information Resource Management .....	40

## **PERSONNEL REQUIREMENTS**

Employee Involvement .....	41
----------------------------	----

## **DATA REQUIREMENTS**

Electronic Data Interchange .....	42
-----------------------------------	----

## **QUALITY ASSURANCE**

Process Quality Assurance .....	42
SPC Supplier Certification .....	42
STAR Preferred Supplier Program .....	43
Supplier Lead Time Reduction .....	43

---

<b>APPENDIX A – TABLE OF ACRONYMS .....</b>	<b>A-1</b>
<b>APPENDIX B – BMP SURVEY TEAM .....</b>	<b>B-1</b>
<b>APPENDIX C – PROGRAM MANAGER’S WORKSTATION .....</b>	<b>C-1</b>
<b>APPENDIX D – NAVY CENTERS OF EXCELLENCE .....</b>	<b>D-1</b>
<b>APPENDIX E – NEW BEST MANUFACTURING PRACTICES PROGRAM TEMPLATES .....</b>	<b>E-1</b>
<b>APPENDIX F – COMPLETED SURVEYS .....</b>	<b>F-1</b>

---

# FIGURES & TABLES

---

## FIGURE

2-1.	1994 Operations Process Costs .....	9
2-2.	Risk Scoring Matrix.....	10
2-3.	Cockpit Review Team Activity .....	12
2-4.	Software Development Process .....	13
2-5.	Integrated Simulation .....	14
2-6.	Design Integration With COMOK.....	15
2-7.	Horizontal Stabilizer Hole Defects .....	19
2-8.	LMTAS Assist Consolidation .....	21
2-9.	Cost Improvement .....	21
2-10.	The Way We Changed –Three Phase Plan .....	22
2-11.	Actions Affecting Life Cycle Costs .....	25
2-12.	Defining Our Future .....	26
2-13.	Improvement Index Structure .....	27
2-14.	Supplier Relationships Through Value .....	28
2-15.	SPC Supplier Commitment Status For Production Supplier .....	30
3-1.	Cost Advantage Architecture .....	36
3-2.	Programs, Functions, and Business Relationships .....	39
3-3.	Improved People Relationships .....	41

---

## TABLES

2-1.	Pollution Prevention Results Through 1994 .....	20
3-1.	Commercial Operating Concepts.....	39
3-2.	System Improvements .....	41

---

# SECTION 1

## EXECUTIVE SUMMARY

---

### 1.1 BACKGROUND

Lockheed Martin Tactical Aircraft Systems (LMTAS) is a government-owned, contractor-operated facility designated as Air Force Plant 4, located adjacent to the realigned Carswell reserve base in Ft. Worth, Texas. This division of Lockheed Martin employs over 11,900 personnel with a 1994 payroll of \$677.76 million. Facilities encompass 602 acres with over seven million square feet of building space. LMTAS supports several major programs including the Air Force's F-16 Fighting Falcon, FS-X, and F-22 Air Superiority Fighter aircraft. In addition, LMTAS is leading Lockheed Martin's effort in the Joint Advanced Strike Technology program to develop future tactical aircraft for the Navy, Marines, and Air Force.

The Best Manufacturing Practices program last surveyed this site in 1988 when the company was the Fort Worth Division of General Dynamics. Many significant practices reported at that time have carried through to present-day programs. For example, the company was ahead of many organizations in addressing environmental concerns - a program that has resulted in millions of dollars saved over the last 7 years. Combining the best of General Dynamics with Lockheed strengths has produced a company that provides its customers with the highest quality products. LMTAS has also developed and enhanced new practices and processes. Its Lean Enterprise Initiative program and a strong relationship with its suppliers have resulted in a rightsized work force and a 38% cost reduction to the F-16 program. These efforts in turn have relied on integration and communication as underlying support mechanisms to execute initiatives and practices successfully.

In 1988, General Dynamics had a corporate strategy of protecting the environment and achieving zero discharge of all hazardous wastes. This policy was forward-looking and successfully generated LMTAS' present-day, proactive emissions remediation management program. More than 50 successful zero-discharge projects have been completed, and pollution prevention initiatives have saved the company more than \$25 million in hazardous waste disposal. The result of LMTAS' environmental program was its selection to receive the Clean Texas 2000 1995 Governor's Award for Environmental Excellence.

LMTAS has remained progressive in its newer programs. Recognizing that Department of Defense dollars would continue to be reduced, LMTAS instigated a Lean Enterprise Initiative in 1991 by first examining and then eliminat-

ing all non value-added costs as they relate to the total weapon system cost. It then outsourced many of its machining, sheet metal fabrication, and other fabrication functions and has become predominantly an assembly and composite fabrication operation with Integrated Product Team participation by its fabrication suppliers. This has allowed LMTAS to actively concentrate on two critical Lean concepts: effectiveness - doing the right things, and efficiency - doing things the right way. Through the Lean Enterprise Initiative and its associated outsourcing program, LMTAS has become more efficient and has reduced the F-16's flyaway price by \$3M per unit.

Outsourcing would not be possible without strong relations with suppliers since purchased material is a high cost driver for LMTAS products, accounting for more than 50% of the total cost. LMTAS has aggressively addressed all aspects of supplier base improvements, communications, and long-term relationships. This program, based on generating objective metrics, is supported by a framework of core programs that improve supplier communications, affect cost/quality/schedule, and establish a certified supplier base. This highly successful supplier relations effort has produced substantial benefits; in particular, the per-unit cost of deliverables has been reduced although total volumes are declining, and 99.9% of all schedules are met while maintaining high levels of performance.

Integration and communication constitute the support infrastructure for these LMTAS programs. These two efforts can be independent or, at times, interrelated. Integrating internal software databases such as those used in the avionics integration process and the Logistic Support Analysis (LSA) program provides access to all personnel involved at any location. Bringing together these personnel who require, share, or access specific data has helped to eliminate duplication of effort and provide a valuable communication tool throughout the organization. This action has led to LMTAS' award in the LSA program of a Blue Contractors Performance Assessment Rating for the past three years.

The BMP survey team considered the early involvement of end users in the design process to be among the best communication practices documented by the BMP program. The company's Integrated Product Development (IPD) effort includes the end user on functional IPD teams to help it produce an effective, efficient product that satisfies the end user's needs. Since 1985, LMTAS has included end users (pilots) as members of its F-16 Cockpit Review

Process to help reduce development costs, improve pilot efficiency, and enhance combat capabilities. This coordination with users constitutes a critical component to ensure that end products specifically address customer requirements. LMTAS' extensive collection of coordinated design processes produce complete "build-to" packages, and also features the use of solid models and process-based cost estimating. These processes not only provide modeling and simulation capabilities for today, but also provide the basis for virtual manufacturing concepts of the future.

Companies such as Lockheed Martin Tactical Aircraft Systems will continue to meet considerable challenges for many years. However, building on past successful practices – like its environmental program – and cultivating current programs such as its Lean Enterprise Initiative and solid supplier relations, LMTAS is adapting to and excelling in a highly competitive arena. Effective integration of databases and end-user communication are strong capabilities that will help LMTAS continue as a premier aircraft production company well into the 21st century. The BMP team considered the following practices among the best in industry and government.

## 1.2 BEST PRACTICES

The BMP survey team documented the following best practices at LMTAS.

Item	Page
<b>Dedicated Cost Team</b>	9
In 1993, the Operations division teamed its Finance counterparts to analyze and comprehend the cost impacts of operations. A cost management organization – the Dedicated Cost Team, comprised of members from Finance and Operations was therefore created within the Operations Department.	
<b>Risk Management</b>	10
LMTAS developed a risk management process to help program managers identify, quantify, evaluate, analyze, and manage in-house and contractor risks to avoid major program delays and higher costs.	
<b>Flight Control Simulation Laboratory</b>	10
LMTAS established an extensive Flight Simulation Laboratory to provide a virtual interface for the evaluation of present and future aircraft operation.	

Item	Page
<b>Modeling and Simulation</b>	11
LMTAS has bundled hardware and software into a tool set to model and simulate many production activities to integrate its Design, Manufacturing, and Business Data Systems into a common information environment.	
<b>Electrical Power System Integration</b>	12
LMTAS addressed a problem of on-board avionics digital computers on the F-16 aircraft improperly handling bus-switching transfers. LMTAS determined that although these transfers were within the limits of MIL-STD-704A, qualification testing was done at the model worst-case level for analog electronics. Lockheed Martin therefore expanded the test requirement for new equipment specifications to provide more detailed information on test method and parameter selection.	
<b>F-16 Cockpit Review Team Process</b>	12
In 1985, LMTAS formed an F-16 Cockpit Review Team to help reduce development costs, improve pilot efficiency, and enhance combat capabilities.	
<b>Software Development Process</b>	13
LMTAS management has focused increased attention on its system software development process. This increased awareness is due to the exponential growth in system software costs measured as a percentage of total system costs	
<b>Conceptual Design Environment</b>	13
LMTAS uses an internally-developed CAD system called Advanced CAD (ACAD) during conceptual design to provide the best opportunity to reduce total product cost. ACAD provides LMTAS the capability to concurrently evaluate manufacturing, tooling, factory, and enterprise concepts with product concepts, and to rapidly construct conceptual virtual prototypes.	
<b>Computer-Aided Three-Dimensional Interface Applications Design Tool</b>	14
LMTAS effectively integrates a suite of design tools to serve specific needs in their respective design environments. The company has selected the commercially-available solid modeling package Computer-Aided Three-Dimensional Interface Applications (CATIA) as the core design software.	

Item	Page	Item	Page
<b>Design Integration with Computer-Aided Mock-Up</b>	15	safety officers, safety assessments of field and manufacturing issues, engineering oversight of flight manual procedures, assistance during in-flight emergencies and expert support of customer mishap investigations.	
LMTAS integrates several design tools to serve company-specific needs. The package Computer-Aided Mock-Up (COMOK) provides an example of enhancing commercially-available CATIA software to satisfy LMTAS specific needs.			
<b>Product Proof and Prototype Validation</b>	15	<b>Shop Floor Statistical Process Control</b>	18
LMTAS has developed a Product Proof and Prototype Validation process to reduce risks associated with product producibility, quality, cost, and schedule prior to rate production.		LMTAS has implemented statistical process control on the shop floor in several applications, and the particular methodology is tailored to best fit the process being monitored.	
<b>Root Cause Analysis</b>	16	<b>Fuel System Simulator</b>	19
LMTAS's Root Cause Analysis program is designed to capture, code, and analyze design change information in support of corrective action plans and process improvement initiatives. The system then provides feedback to quality-related corrective actions.		LMTAS has developed a Fuel System Simulator as an important tool in conducting aircraft fuel systems testing. Innovative design and fabrication procedures used in the design and building of simulated fuel tanks for the F-22 Fuel System Simulator are helping improve quality and lower program costs.	
<b>Engineering Source Data Requirements</b>	16	<b>Hazardous Material Management</b>	20
As the result of increasingly complex aircraft design and proliferation of unique groups of F-16s, LMTAS implemented Engineering Source Data Requirements Process in 1991 to help personnel more effectively manage engineering data.		Since 1984, pollution prevention initiatives have saved LMTAS more than \$25 million on hazardous waste disposal, and the company was selected from a field of 70 large technology companies to receive the Clean Texas 2000 1995 Governor's Award for Environmental Excellence.	
<b>Avionics Systems Integration</b>	17	<b>Asset Consolidation</b>	21
Avionics Systems Integration has evolved from a series of formal tests verifying each step in the development of the Operational Flight Program to a single, formal sign-off at the avionics system level.		LMTAS has deactivated floor space and reduced its manufacturing area by 800,000 square feet, thereby greatly reducing electrical power, heating, and air conditioning expenses to those sections. In addition to the utility cost savings in the manufacturing area, LMTAS has reduced major machinery inventory by 191 pieces.	
<b>Logistics Support Analysis Program</b>	17	<b>Integrated Product Development</b>	21
LMTAS uses a teaming process for communicating and sharing information necessary to develop a successful Logistics Support Analysis program and database. Bringing together all parties who share, need, and/or access specific data has helped eliminate duplication of effort throughout the organization and resulted in a quality product that meets the needs of all the users.		The LMTAS IPD philosophy teams functional disciplines to integrate and concurrently apply processes to produce an effective, efficient product that satisfies a customer's needs. It requires a strong partnership among contractor, customers, and suppliers.	
<b>Aerospace Safety Program</b>	18	<b>Lean Enterprise Initiative</b>	22
The Aerospace Safety Program promotes flight safety of LMTAS products through unique, regularly scheduled teleconferences with customer		The LMTAS Lean Enterprise Initiative is a three-phased, major reengineering effort begun in 1991 and is based on <i>effectiveness</i> - doing the right things, and <i>efficiency</i> - doing things the right way.	

Item	Page	Item	Page
<b>Modified Requirements Contracts</b>	<b>23</b>	<b>Product Definition and Design Metrics</b>	<b>26</b>
LMTAS addressed several pricing concerns with a goal to maintain aircraft unit price as production levels decline. Its suppliers recommended Modified Requirements Contracts and, although it primarily covers low cost commercial products, LMTAS decided to apply this to its more costly defense products.		Extensive use of metrics within the Product Definition and Design Business System at LMTAS provides a management and tracking system to measure performance against goals and objectives.	
<b>Factory Layout Planning Techniques</b>	<b>23</b>	<b>Internal Review Process</b>	<b>27</b>
Tactical aircraft manufacture requires a detailed factory layout because of the aircraft's physical size, associated tooling, and the location within the manufacturing process flow. LMTAS produces its facility layout in three-dimensional space using an Intergraph workstation. The factory floor layout is entered, and then 30 solid models are inserted representing all tooling and material handling devices.		The Internal Review Process at LMTAS is a functional and/or cross-functional review activity that seeks to establish compliance of each product with its corresponding set of product requirements.	
<b>MRP II</b>	<b>24</b>	<b>Supplier Relations</b>	<b>27</b>
Examining its internal processes and the downstream effect of other organizations within the company, LMTAS has evolved its MRP II system into a total operations control and accounting system providing data that benefits all of the Operations Division.		LMTAS has established an aggressive and comprehensive Supplier Relations Program to develop and continuously improve a strong supplier base that provides low cost, high quality products that are delivered on time.	
<b>Ergonomic Tooling/Manufacturing</b>	<b>24</b>	<b>Supplier Rating System</b>	<b>29</b>
Originally chartered to reduce cumulative trauma injuries, the Ergonomic Organization reviewed factory processes, and those tasks that surpassed human capabilities were found to directly correlate to cumulative trauma. Working with the factory floor personnel, these identified tasks were changed by either altering the existing processes or by procuring ergonomically-designed tools that reduced the cumulative trauma potential.		LMTAS's supplier rating system is based on how well the supplier is performing compared with its own abilities. Two basic parameters are used to measure the supplier's performance – purchase order delivery schedule and quality performance.	
<b>Goal Deployment</b>	<b>25</b>	<b>Supplier Statistical Process Control</b>	<b>29</b>
LMTAS goals and objectives are defined yearly, documented, displayed throughout the facility, and translated into individual employee objectives down through the organizational chain. Employee performance ratings and rewards reflect how well employees are meeting their objectives, and no quotas exist on any level of performance rating.		The goal of this LMTAS supplier program is to ensure that the company's suppliers use statistical process control techniques to reduce cost and improve product quality.	
		<b>Supplier Performance Evaluation and Review Program</b>	<b>31</b>
		LMTAS has established a new program to monitor suppliers whose performance falls below required levels. This effort highlights cooperation between LMTAS and the affected suppliers so satisfactory performance can be restored and long term relationships maintained.	
		<b>F-22 Variability Reduction</b>	<b>31</b>
		LMTAS has established a variability reduction program to meet a contractual requirement of the F-22 program under which the variability reduction program and related activities are designated as award fee criteria.	

Item	Page
<b>On-Call and Just-In-Time</b>	<b>31</b>

The On-Call and Just-In-Time programs help affect the goal of reducing inventories to zero levels. The On-Call program applies to more than 240 contracts covering 6000 line items. The Just-In-Time program was started three years ago and applies to two large contracts covering 1000 line items.

<b>Continuous Performance Improvement</b>	<b>32</b>
---	-----------

A multifaceted, structured approach has been developed to achieve the LMTAS' Quality Policy #1 objective. This approach is based on a four-quadrant plan to capture, plan, facilitate, and implement continuous improvement throughout the organization.

<b>Supplier Integrated Product Development</b>	<b>33</b>
--	-----------

The Supplier Integrated Product Development Source Selection Process provides a well-defined set of program requirements as well as the basis for proposal preparation. It also supports the philosophy that a proposal can be prepared with complete understanding of and agreement with the requirements.

<b>Outsourcing of Non-Core Processes</b>	<b>33</b>
--	-----------

In response to the decline in budgeted dollars allocated for defense programs, LMTAS initiated cost and risk reduction by outsourcing nonstrategic tasks such as machining, sheet metal part fabrication, and electrical fabrication. This outsourcing process provides quality products at a reduced cost.

### 1.3 INFORMATION

The BMP survey team highlighted these information items at LMTAS.

Item	Page
<b>MRP Purchasing Management System</b>	<b>35</b>

The MRP II system at LMTAS is an electronic closed-loop system that maintains cost accountability for the material flow process. It efficiently provides the correct quantity of required materials at the needed time and place, and maintains accurate records of all material flow information.

Item	Page
<b>Automated Budget Control System</b>	<b>35</b>

The Budget Control System increases the speed and efficiency with which high-volume procurements are initiated and approved. This new system, in use since 1994, has been effective not only in streamlining the purchase order process but also in increasing accountability for those purchases made.

<b>Process Quality Policies</b>	<b>35</b>
---------------------------------	-----------

LMTAS' successful efforts in improving process quality have included establishing Integrated Process Teams and new management positions, instilling manufacturing discipline, and applying Process Quality Policies. These actions have contributed to a significant schedule improvement and a reduction in production cycle times through concurrence of traditional engineering and Manufacturing Engineering tasks.

<b>Design Cost Integration</b>	<b>36</b>
--------------------------------	-----------

LMTAS is beginning a new effort to develop a tool set that will provide an integrated approach to bringing all aspects of costing such as engineering, material, and manufacturing together through a central interface.

<b>Product Modeling and Simulation</b>	<b>36</b>
--	-----------

LMTAS extensively uses product modeling and simulation to improve product development and communication, and to more effectively serve the customer's needs.

<b>Variability Reduction</b>	<b>37</b>
------------------------------	-----------

The objective of the variability reduction process at LMTAS is to improve the quality of products and services by minimizing variations in their manufacturing processes. This process is becoming institutionalized within the company and provides a set of tools and procedures for achieving variability reduction.

<b>Process Development Center</b>	<b>37</b>
-----------------------------------	-----------

LMTAS has recently opened a composites Process Development Center to give it an innovative, integrated, interdisciplinary development center for achieving excellence in composites products and processes.

Item	Page	Item	Page
<b>Research and Engineering Learning Resource Center</b>	37	<b>Information Resource Management</b>	40
The Research and Engineering division of LMTAS has developed a learning resource center which focuses on computer-led training as opposed to the traditional classroom, instructional training.		The role of the Information Resource Management organization at LMTAS is to provide information technology to support the requirements of the core business systems, much of which is accomplished through a unique outsourcing relationship.	
<b>Flight Control Systems Teaming</b>	38	<b>Employee Involvement</b>	41
Teaming was successfully applied to the complex flight control systems development processes on the AFTI/F-16 in 1980. Since then, a number of lessons have been learned that provide insight into teaming relationships.		LMTAS is working to maintain productivity and improve the quality of its work environment as it accepts the challenge to create a lean manufacturing environment. While it improved schedules and cost, LMTAS management realized that it must listen to the needs of the factory workers and encourage communication among all tiers of personnel.	
<b>Commercialization</b>	38	<b>Electronic Data Interchange</b>	42
To address the growing need for acquisition reform and streamline the acquisition process, LMTAS has proposed to apply commercial business practices to its existing F-16 production program under a pilot plant program.		LMTAS has initiated electronic data interchange with members of its supplier base for electronic exchange of routine business documents.	
<b>Product Definition and Design Business System</b>	39	<b>Process Quality Assurance</b>	42
LMTAS is evolving its organizational structure to support a product definition and design business system supplying proven build-to packages to a product delivery system. This effort will streamline the procurement, fabrication, assembly, and delivery of tactical aircraft and related systems.		LMTAS' Process Quality Assurance Organization uses an integrated team approach to resolve manufacturing anomalies. This team has the responsibilities of eliminating or minimizing causes of nonconformance and developing corrective actions that identify necessary actions, assigning implementation activities, and establishing completion dates.	
<b>Quick Reaction Procurement</b>	40	<b>SPC Supplier Certification</b>	42
The Quick Reaction Procurement process was developed specifically to address purchase orders of less than \$2.5K. The system incorporated online documentation, signature authority, eliminated storage space, reduced hard copy requirements, and blanket purchase agreements were established to streamline the process.		The SPC Supplier Certification program is an initiative under the LMTAS Supplier Relations Program requiring that all suppliers use statistical methods and techniques to analyze their processes and outputs for reducing costs and improving product quality.	
<b>Electronic Procurement Process</b>	40	<b>STAR Preferred Supplier Program</b>	43
LMTAS has been developing an Electronic Procurement Process since 1994 with numerous objectives, among the most important to decrease cycle time and create a central procurement processing capability. The key to the LMTAS approach is to connect the procurement process with the supplier electronically.		LMTAS' preferred supplier program helps decrease costs associated with ensuring acceptable quality from its suppliers, while enhancing the suppliers' confidence levels.	

---

Item	Page	<b>1.4 ACTIVITY POINT OF CONTACT</b>
<b>Supplier Lead Time Reduction</b> LMTAS's initiated a schedule review program called Supplier Lead Time Reduction to reduce the production cycle of an aircraft assembly from 42 months to 24 months.	43	For further information regarding any item in this report, please contact:  John A. Horton Project Manager Process Engineering Lockheed Martin Tactical Aircraft Systems Post Office Box 748 Mail Zone 6494 Ft. Worth, Texas 76101 (817)763-3060 FAX: (817)777-1107 Internet address: <a href="mailto:connerjg@cliffy.lfwc.lockheed.com">connerjg@cliffy.lfwc.lockheed.com</a>

---

# SECTION 2

## BEST PRACTICES

### 2.1 FUNDING

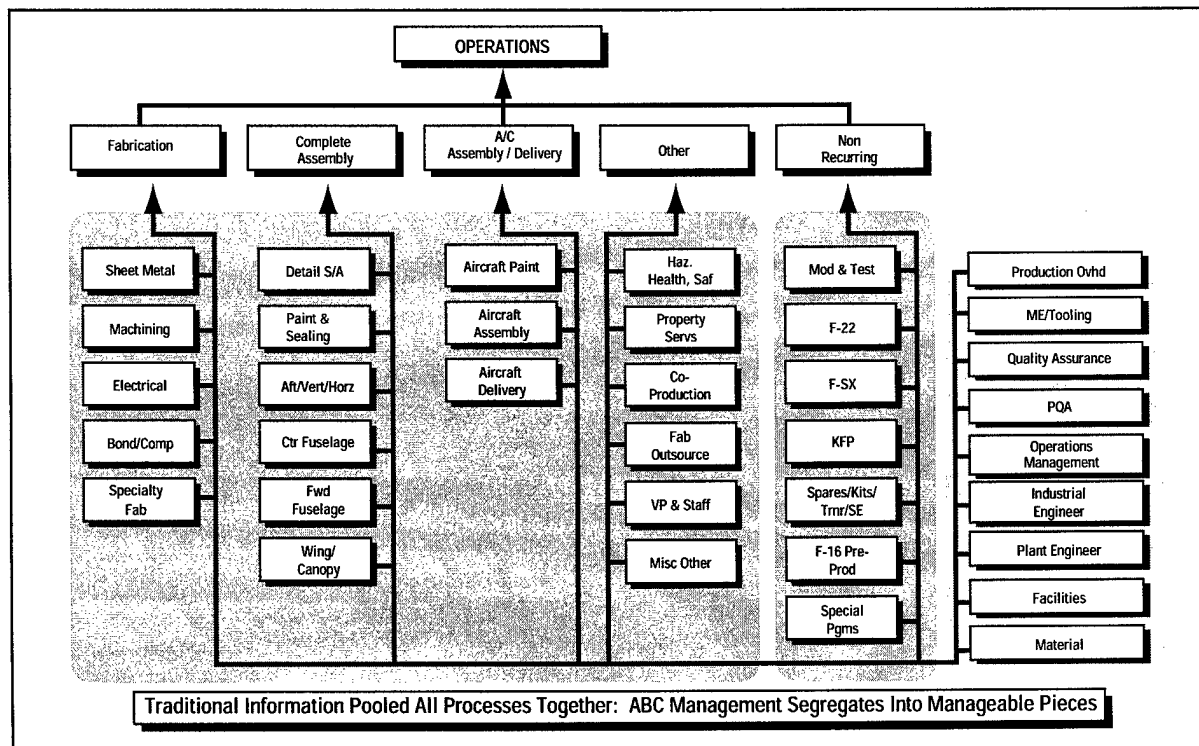
#### COST ASSESSMENT

##### Dedicated Cost Team

When Lockheed Martin Tactical Aircraft Systems (LMTAS) made the strategic decision in the early 90s to become a Lean Manufacturer, the company recognized that the goal would require significant improvement in productivity, systems, quality, schedule, and cost. These improvements would also have to be realized within a declining business base environment. Cost quickly became the primary metric in this phased approach to implementing Lean Manufacturing initiatives. In 1993, the Operations division teamed its Finance counterparts to analyze and comprehend the cost impacts of operations. A cost management organization – the Dedicated Cost Team, comprised of members from Finance and Operations – was therefore created within the Operations Department.

The purpose of this Dedicated Cost Team was to identify areas of opportunity and then plan and implement strategies for continuous improvement. Cost was used as a basis for restructuring the organization. Best practices often based on input from production workers were identified and implemented, and direct cost teams worked to identify and track all elements of cost on the factory floor. A support cost team was established to do the same for support costs. As cost drivers became understood, cost metrics became a tool for control and improvement. A bottom-up plan was developed that included detailed management of cost at all levels.

Two important concepts that guided LMTAS to success as a Lean Manufacturer were “Beans in the Box” and Cost Per Equivalent Unit (CPU). Beans in the Box was also known as Activity-Based Cost (ABC) Management. Traditional accounting methods combined all processes in cost pools such as Direct Labor, Overhead, Fringe Benefits, other charges, Material, and G&A cost drivers. ABC management instead segregates cost information into more detailed but manageable pieces. Figure 2-1 illustrates how



**FIGURE 2-1. 1994 OPERATIONS PROCESS COSTS**

operational process costs are broken down. This approach provides resource managers improved cost management data, is flexible, and results of changes are quickly discernible. Under ABC management, manpower is assigned to particular manufacturing processes. Cost management data is used to challenge management and support ratios, and drives decisions to outsource. The data is also tied to the MRP system and helps determine increases or decreases to staffing levels.

The CPU attempts to capture all costs of an aircraft, and is intended as a consistent and reliable method to determine if reduction of aircraft costs is being achieved. Since 1991, production at LMTAS has decreased by more than 50%, yet the CPU has remained constant. Activity-Based Cost management has made it possible to reduce or eliminate most non-value-added cost drivers, enabling LMTAS to reduce the flyaway cost to the government by \$3 million per aircraft for the F-16.

An automated operations financial system was brought on line in 1994 to help all levels of Operations personnel receive financial data in a timely manner. It is used to control Operations efficiently and helps drive continuous improvement.

## Risk Management

LMTAS has developed a risk management process to help program managers in such programs as the F-16

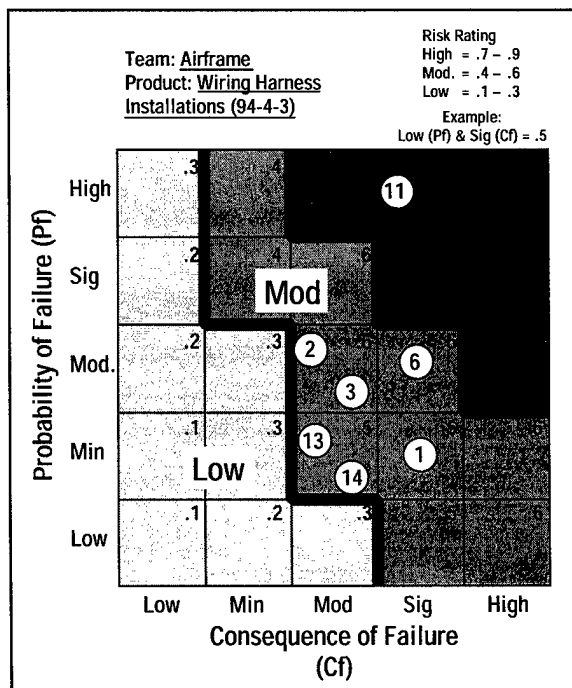


FIGURE 2-2. RISK SCORING MATRIX

aircraft. This risk management process helps identify, quantify, evaluate, analyze, and manage in-house and contractor risks that – if unattended – could cause major program delays and higher costs.

LMTAS orients risk assessment around the product work breakdown structure (WBS). Risk consists of two components – the probability of failing to achieve a particular outcome and the consequence of failing to achieve that outcome. Each component is assigned a five-tiered risk rating (low, minor, moderate, significant, and high), and a Risk Scoring Matrix is developed (Figure 2-2) from the two risk components and the rating criteria. Risk assessment templates are prepared for each element of the WBS by identifying the risk drivers such as design maturity, producibility, process metrics, plans, resources, manpower, and funding. Each risk driver for each element of the WBS is plotted on the Risk Scoring Matrix. From this matrix, abatement (or risk prevention) activities are planned for high, moderate, and low risks, as required. A risk plan (a graph of risks versus time line) is made as a management tool to ensure that risks are being addressed in a timely manner.

This risk analysis process helps to clearly identify the best contractor, ensure the contractors are treated fairly, and provide substantial source selection justification in the event of a protest. A schedule risk analysis can also be plotted for each task relationship in the program to show sensitivity between program schedules and tasks.

For highly interrelated task networks or a WBS with several elements, this method allows metrics to be used for decision making. Because of this decision-making process program, cost and schedule savings can be realized.

## 2.2 DESIGN

### DESIGN REFERENCE MISSION PROFILE

#### Flight Control Simulation Laboratory

LMTAS established an extensive Flight Simulation Laboratory and developed supporting project teams to interface with end users and customers. The Flight Simulation Laboratory provides a virtual interface for the evaluation of present and future aircraft operation.

The \$100M Flight Simulation Laboratory is housed within a 112,000-square foot area. The environmentally-controlled lab contains 22 simulators for six major aircraft systems (F-22, F-16, F-111, AFTI, VISTA and the Joint Advanced Strike Technology program). The laboratory also contains multiple host computer systems, special purpose processors, multipurpose computer graphic systems, 13 digital visual image processors, and digital databases for Fulda Gap (Germany), Edwards Air Force Base, Nellis Air Force

---

Base, and Kantchatka. The Flight Simulation Laboratory has a variety of tools to support the design process including seven Concept Development Stations with reconfigurable cockpit stations for the F-16. Each has a 30° by 40° visual projection (one or three channels).

These stations are operated at low cost with quick reaction modification for early design concept evaluations. Software is also transportable to other simulators.

Among the stations:

1. Each *Air-to-Ground Dome Station* contains a cockpit setup inside a 24-foot diameter dome. The projection system features six projectors with a field of view of 240° horizontal by 115° vertical and full mission capability, pilot training, mission effectiveness, and networking for multi-aircraft evaluation.
2. The *Multipurpose Dome Stations* also have cockpit setups within 24-foot domes. Each dome has three projection systems for front-hemisphere, aft-hemisphere, and high-resolution, 40° horizontal by 30° vertical inset in front of the pilot. They provide the same capabilities as the Air-to-Ground Dome Stations.
3. The *Handling Qualities Stations* have three cockpit stations with a field of view of 120° horizontal by 35° vertical, and one cockpit station with a 170° horizontal by 60° vertical on a 20-foot diameter dome. These stations extensively use analog and digital recording with the capability for evaluation of aerodynamic data.
4. There are two networked 40-foot domes known as *Air Combat Simulators*. Target models can be projected within the dome in a friendly or enemy configuration. Some cockpits have a capability for immediate reconfiguration to design customer requirements and simultaneous evaluation.

The simulation and reconfiguration of controls and software at the front end of a program, along with customer evaluation, provide the most economical means to meet pilot needs. This simulation also reduces flight test times during planned modification.

The Project Teams that support this Flight Simulation Laboratory encompass engineering, design, fabrication, and maintenance for pilot-vehicle integration. For example, for coordination of information, the Project Team forms a Simulation Integration Review Team (SIRT) composed of the Engineering Design Group (with a Pilot-Vehicle Integration Coordinator) and a Flight Simulation Laboratory Integration Group (with a Flight Simulation Laboratory Project Leader). The Engineering Design Requirements Group addresses system design, human factors, the crew station, controls and displays, safety, and flight controls. The Flight Simulation Laboratory Integration Group has

responsibility for maintenance and support, equipment design, systems engineering, simulation software support, and mission planning systems. The associated Group coordinator and project leader coordinate and direct the information for the SIRT. The SIRT also has the responsibility for evaluation of F-16 avionics software configuration.

## DESIGN REQUIREMENTS

### Modeling and Simulation

LMTAS has bundled hardware and software into a toolset for modeling and simulating manufacturing processes during design in preparation for production. LMTAS is using modeling and simulation to integrate its design, manufacturing, and business data systems into a common information environment. This integration provides a common data path between functions and enhances evaluation of complex design, manufacturing, and business concepts during all phases of the product's life cycle. Factory layout, functional verification of tools, interference detection of assemblies, and manufacturing process concept development are tied together by a three-dimensional solid model.

Workstations, PCs, and software tools such as AUTOMOD, ACAD, ERGO, CATIA/COMOK, Excel, and SLAM provide manufacturing process simulation capability used in product design. Operational simulations of flight, carrier operations analysis and visualization of flight recorder data are also used. Networking and solid modeling of the product in CATIA/COMOK provide a common path for information sharing and simulation. An organizational realignment which integrated manufacturing engineering tasks into the design department provide early awareness and leverage of manufacturing issues in product design. Tool jigs and fixtures concepts are developed and functionally simulated during advanced design to highlight configuration or concept problems. Weight and cost data can be reviewed to trade options, or detailed part configuration information such as radii can be evaluated for economical machining. Solid modeling of products, parts, and processes allow fit checks and evaluations of interferences and ease of assembly using COMOK. High level assembly efforts are simulated using discrete event simulation software (SLAM) to assess efficiency and highlight improvement opportunities.

The traditional method of manufacturing allowed very little cross-functional technical interface. The virtual manufacturing method provides a simultaneous interface between all technical disciplines and provides better communication of complex designs, manufacturing, and business concepts. The product consequently requires a shorter cycle time, lower development costs, improved quality, and encourages more team ownership.

## Electrical Power System Integration

LMTAS addressed a problem of on-board avionics digital computers on the F-16 aircraft improperly handling bus-switching transfers. Although these computers were designed and qualified to the electrical power requirements of MIL-STD-704A and met the requirements when tested separately, anomalies were experienced when integration of the total aircraft electrical system was attempted.

LMTAS determined that although these transfers were within the limits of MIL-STD-704A, qualification testing was done at the model worst-case level for analog electronics (0 volts, 50 msec). This qualification testing did not account for bus transfers that were faster than the worst case scenario. This faster electrical transfer rate would cause multiple power-up, power-down conditions, and would cause corruption of the computer software, creating the integration problems.

Lockheed Martin therefore expanded the test requirement for new equipment specifications to provide more detailed information on test method and parameter selection. This specification requirement now verifies specified operation for total power capacity consumed, steady-state voltage limits, normal and abnormal transients (multiple test points throughout each allowable envelope), and power transfers (multiple test points). Besides expanding the test requirements, LMTAS built a fully instrumented test bench to simulate and duplicate all F-16 aircraft electrical systems. This test bench can duplicate different aircraft power generation systems and vary the performance of each generation system within its design parameters. The use of this test bench is offered to all prime groups and suppliers for electrical system integration testing.

By duplicating the aircraft power system and its variances, specifying test conditions and parameters, and then integrating the complete electrical system, LMTAS has identified MIL-STD-704A noncompliance issues during hardware development and qualification testing. This has allowed the company to eliminate cost and schedule impacts created when noncompliance is identified after hardware delivery. Electrical system integration can be accomplished in a laboratory environment before a production break-in, eliminating corrective actions needed after initial aircraft production and field use.

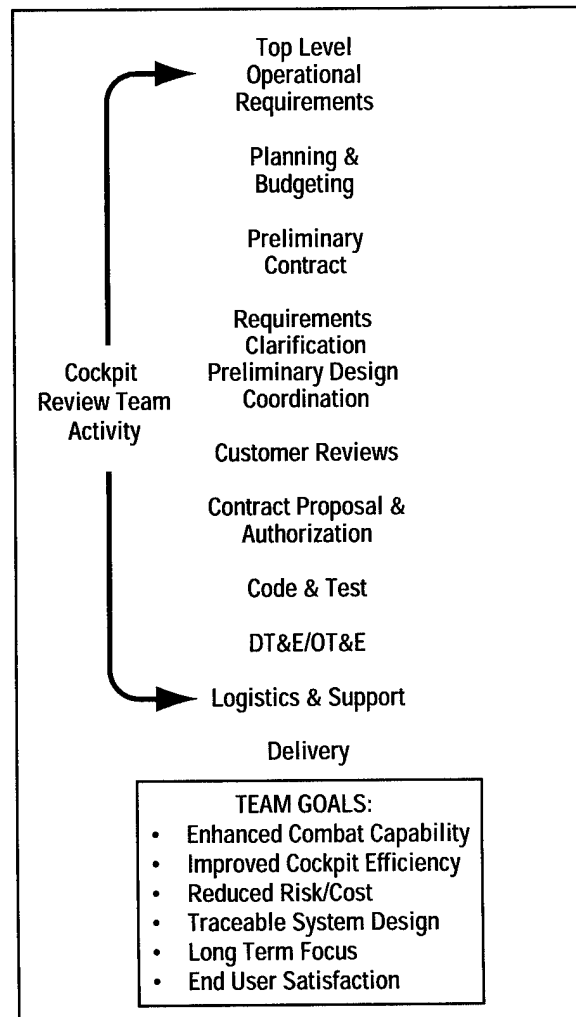
## DESIGN POLICY

### F-16 Cockpit Review Team Process

In 1985, LMTAS realized that the F-16 cockpit was becoming more complex, and a new design approach would have to be enacted to ensure that the end product would meet the needs of the customer and still enable the pilot to better

perform his mission. A more formal process was needed to help reduce development costs, improve pilot efficiency, and enhance combat capabilities. That recognition resulted in the formation of the Cockpit Review Team for the F-16 program.

The typical Cockpit Review Team is comprised of representatives from the F-16 Systems Program Office, Headquarters Air Combat Command, Air Force test centers and LMTAS personnel. The team's activities are incorporated from the initial top-level operational requirement to final delivery (Figure 2-3), and the process begins with a review of suggested improvements and ideas submitted by those who fly the F-16 aircraft. These suggestions are then integrated with Air Force headquarters requirements, and a prioritized list is developed for the first examination by the Cockpit Review Team.



**FIGURE 2-3. COCKPIT REVIEW TEAM ACTIVITY**

LMTAS conducts initial design work, develops a cost estimate for each of the new capabilities listed, and prepares the F-16 simulators for actual pilot evaluations. These simulations, with ideas and suggestions from the pilots, are then used to finalize the contractual requirements for a given aircraft development or system update. The benefits that are obtained using this structured, up-front process have led to the adaptation of similar processes for other Air Force aircraft programs such as the F-15E, A-10 and C-17. By involving pilots early in the design process, customer acceptance and satisfaction have been greatly increased.

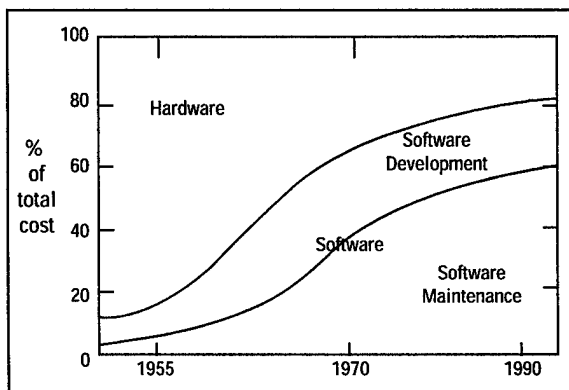
## SOFTWARE DESIGN

### Software Development Process

LMTAS management has focused increased attention on its system software development process. This increased awareness is due to the exponential growth in system software costs measured as a percentage of total system costs (Figure 2-4). In mid-1991, LMTAS chartered a Software Engineering Process Group (SEPG) to implement, assess, and improve the standard software development process. This effort, based on the Software Engineering Institute Capability Maturity Model, maintains a goal of producing high quality software at a reduced cost.

Application criteria for this standardized process are generally based on project scope and magnitude. For example, existing projects may only require limited application, while new projects require evaluation based on their magnitude and expected life cycle. However, projects of more than 2000 work hours and over 6 months are required to apply the standardized software development process.

The SEPG works to control and maintain development standards, provide training, and assist in the categorization and customization of the development process used to create software. The SEPG also serves as a focal point for



**FIGURE 2-4. SOFTWARE DEVELOPMENT PROCESS**

technology application of appropriate software methods as well as automated Computer-Aided Software Engineering tools. Object-oriented programming is applied where appropriate.

The SEPG maintains a central database of project descriptions and metrics that are used to assess the software development process. Measurements may include typical project measures such as schedule and cost performance as well as software-specific measures – stability, defect density, and computer resource utilization. Measurable successes include being independently assessed as Software Engineering Institute Level III in 1993, and achieving a 25% reduction in software costs within 2 years of process implementation.

## COMPUTER-AIDED DESIGN

### Conceptual Design Environment

LMTAS uses an internally-developed CAD system called ACAD during conceptual design to provide the best opportunity to reduce total product cost. ACAD provides LMTAS the capability to concurrently evaluate manufacturing, tooling, factory, and enterprise concepts with product concepts, and to rapidly construct conceptual virtual prototypes. These virtual prototypes are used for early cost evaluation. ACAD also has an interactive capability through high-speed data transfer lines with other sites to provide real time, individual interaction with all connected sites.

Development of ACAD was initiated in 1982 and now contains over 800,000 lines of code. The effort was undertaken because there were no commercial tools for LMTAS's needed capabilities. ACAD's customized features include:

- Rapid lofting of advanced surfaces
- Geometric associativity to facilitate rapid iterative design modifications
- Rapid area, volume, and center of gravity analysis tools
- Aerodynamic center analysis
- Advanced meshing interface to RCS and CFD
- Rapid structural modeling - weight and cost prediction
- Carrier suitability analysis tools
- Stereolithography interface
- Obscuration (vision) plots
- Rapid solid modeling
- Ray tracing cavity analysis
- Built-in animation/simulation tool.

The ability to rapidly generate multiple structural models with associated weight and cost estimates is a major benefit

for design optimization in the early stages of product development. Integrated simulation (Figure 2-5) allows many assembly and manufacturing processes to be proofed well in advance of hardware availability, thereby avoiding costly fabrication of mock-ups.

### CATIA Design Tool

LMTAS effectively integrates a suite of design tools to serve specific needs in their respective design environments. The company has selected the commercially-available solid modeling package CATIA as the core design software. The LMTAS design process consists of conceptual, detail, and production design processes. The design software used in this process consists of the internally-developed ACAD for conceptual design to CATIA for detailed design. In some instances, the commercially-available CADAM is applied for two-dimensional design.

Because CATIA is the core design tool for LMTAS, it is used extensively to produce product designs, computerized mock-ups, tooling design, flat pattern layouts, tube and wire routings, and automated drawing generation, as well as performing numerous other design functions. It is used

throughout the organization for preliminary and production design, NC programming, NC tool fabrication, and quality assurance. Advanced functions include parametric modeling, generating NC code from solid models, concurrent associativity, automatic meshing, exact solid models, transparent analysis, and feature-based modeling.

Although CATIA effectively serves the core design functions, LMTAS requires customized software to perform the database management tasks within this design environment. For this purpose, LMTAS created the Consolidated Product Data Base which consolidated the previously segregated CATIA databases used for planning, engineering, manufacturing, and tooling into one database that manages these functions. It also provides configuration management and release functionality. It is effectively used to manage the build-to package throughout the integrated product development process.

In developing this capability, LMTAS has had high-level meetings with management of the CAD vendor to discuss strategic directions and ensure that future software evolves into the proper functionality. Although LMTAS has constructed the missing links of commercially-available software and effectively integrated these to serve Lockheed

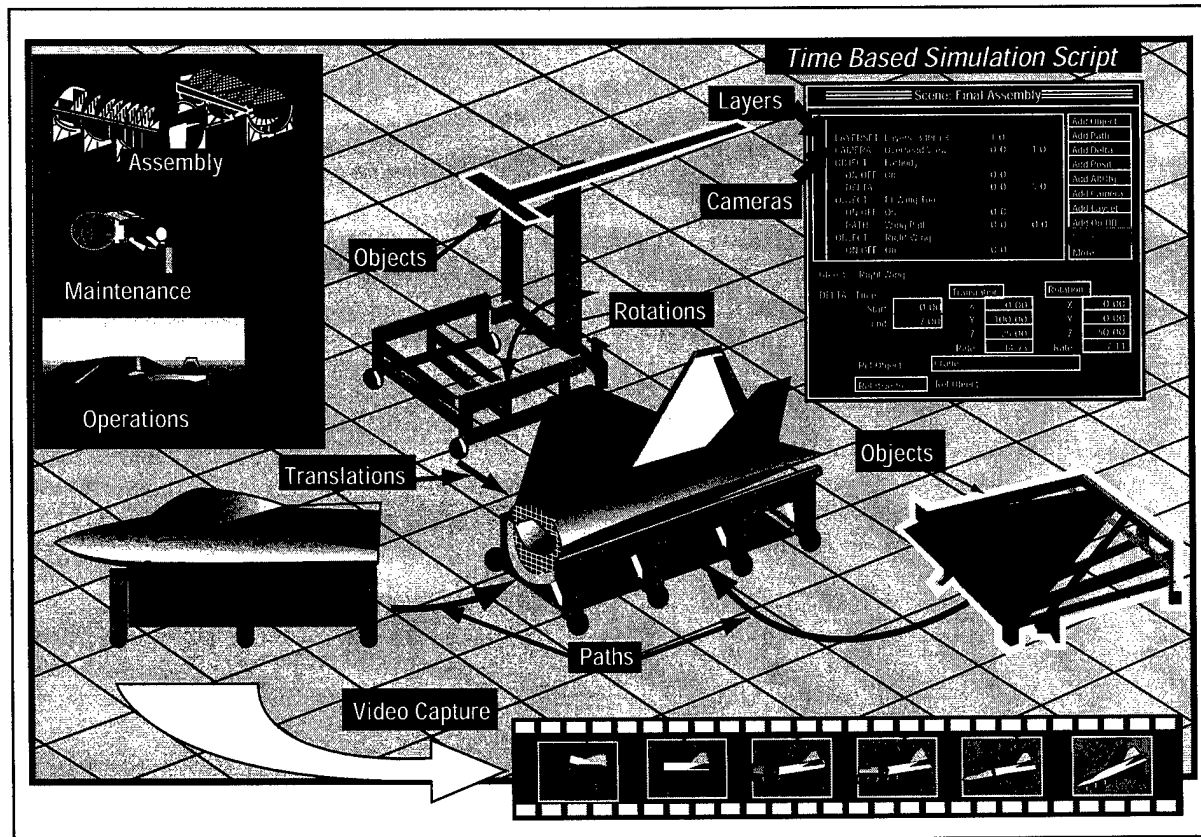


FIGURE 2-5. INTEGRATED SIMULATION

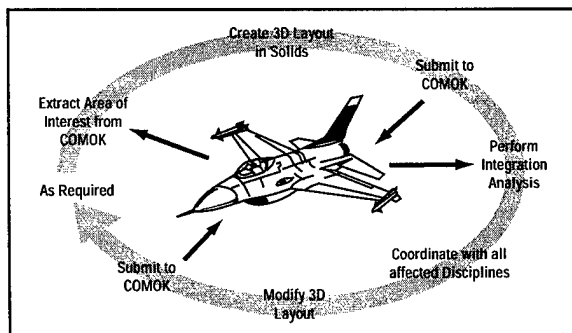
needs, the company maintains that it is still more efficient for the commercial software developer to provide as much functionality as possible. Standards must also be enforced and incorporated early in the design to allow for multiorganizational use of product definition data in a format that facilitates data management.

## Design Integration with COMOK

LMTAS integrates several design tools to serve company-specific needs. For example, LMTAS selected CATIA (a solid modeling package) as the core design software. LMTAS has identified several specific design functions not available with commercial software and has chosen to customize or build software to serve these specific needs. COMOK provides an example of enhancing commercially-available CATIA software to satisfy LMTAS specific needs.

Although CATIA is a robust design tool, it did not satisfy all LMTAS integrated product development needs. Concurrent, integrated product development is enabled by the dynamic sharing of design iterations. The COMOK database management system is the technology that provides centralized access to multiple configurations defined geometrically by CATIA solid models. As new programs are initiated, COMOK is used in place of metal mock-ups. Since it is available at the start of the design process, it improves design integration and quality.

As COMOK provides a tool for design integration, it also serves to cross organizational boundaries, integrating the conceptual and detail design with the manufacturing and assembly process development (Figure 2-6). The digital database is populated by engineering and tooling component iterations throughout the development phase of a program, and is used by many functions within the integrated product teams. As component parts are integrated, COMOK provides automated utilities checks for interferences and clearance requirements. With this integrated product development functionality, COMOK is used to communicate design changes to those affected. After the design has been



**FIGURE 2-6. DESIGN INTEGRATION WITH COMOK**

released, the database is used for follow-on design and analysis activities throughout the product's life cycle.

LMTAS realized the implications of limiting access to the conceptual model during the fluid design phase. As a result, it has few restrictions governing the modification of component parts in the fluid design phase. Once the design is finalized, it is released and changes are accomplished within Engineering Change Notice guidelines.

COMOK is currently implemented on the FS-X, F-22 (team-wide), F-16U, and F-16 Singapore programs with over 900 active participants. The F-22 program takes the integrated functionality one step further by allowing the design partners such as Boeing, Lockheed Marietta in Georgia, and LMTAS to share common data during the integrated product development phase. On this program, there are approximately 1400 megabytes of information shared between the multi-company partnership.

The design integration has had a significant and positive impact on quality, schedule, and cost. Quality improvements are realized through fewer design iterations, a well-integrated product, maximum data reuse, fewer "surprises," and verification of design and tooling integration. This product performs schedule compression as planning, design, analysis, and manufacturing planning are performed concurrently. On the F-16 program, design change cycle time has been reduced from 8 months to 3 months. Also, the need for metal mock-ups is essentially eliminated.

## DESIGN REVIEWS

### Product Proof and Prototype Validation

LMTAS has developed a Product Proof and Prototype Validation (P3V) process to reduce risks associated with product producibility, quality, cost, and schedule prior to rate production. Ultimately, this process should ensure that the design intent is conveyed in a clear and understandable format to the user and can be manufactured and installed repeatedly on a reliable basis at rate production. The design intent is conveyed through the build-to package which consists of the engineering package, work instructions, production tools, and manufacturing processes. P3V is an excellent process for proofing the engineering design prior to formal release. This multifunction process requires management commitment from all functions performing the various tasks.

The most basic element of proofing is the application of a new level of rigor to the "checking" systems. This may include proofing the engineering design, tool designs, and work instructions. It may also include first article inspection and fit checks for component assembly and installation. The proprietary LMTAS software COMOK and Hard Mock-up are other examples of proofing tools.

Under the P3V process, risk assessments are performed at various stages of the proofing process to evaluate the need for proofing, to forecast the proofing level, and to verify that specified proofing has been accomplished. Information obtained during the initial risk assessment provides input for constructing a critical path schedule that includes proofing activities, verification of a proofed process, and formal release. The scheduled proofing plan is a part of the proposal that is submitted to the customer. Proofing activities continue throughout product development until the final prototype is validated against the formally-released engineering specifications. The parts remain in proof status until the P3V process, first article inspection and installation (fit check) are completed. Significant savings in scrap and rework cost can be obtained by limiting rate production until this process is complete.

In addition to product development, other proofing activities include trial verification installation to proof retrofit kits and engineering evaluation tests for proofing support equipment.

The F-22 program has benefited from this rigorous process as high-risk component parts are identified and categorized for the P3V process. For suppliers, P3V requirements for high-risk parts are imposed through the purchase order. For in-house manufacturing, P3V requirements have been added to the planning manual in the form of inspection and verification plans. Also, proofing requirements are integrated into the work instructions and planning documentation.

There are several examples of successful P3V application on the F-22 program. For example, titanium bulkheads are large machined forgings measuring 6 feet by 15 feet that are extremely complex to machine with wall thicknesses as thin as 0.050-inch. A typical bulkhead has 3000 to 4000 attributes and, on an average, the supplier-delivered bulkheads had only two or three defects. This is an average yield of greater than 99.5% which is unprecedented for comparable machining processes.

## CONFIGURATION CONTROL

### Root Cause Analysis

LMTAS's Root Cause Analysis (RCA) program is designed to capture, code, and analyze design change information in support of corrective action plans and process improvement initiatives. The RCA system provides feedback to quality-related corrective actions in support of the LMTAS Quality Policy #1 (QP#1) goal of ensuring that all engineering products and services are correct and complete before release.

In April 1992, a computerized system was implemented to ensure that Engineering Change Notices would automatically trigger the capture of root cause information. The

RCA system was linked electronically to the engineering release system to automatically prepare RCA records for specified engineering documents.

RCA codes were developed to document and categorize the *type* of design change as well as the contributing *cause*, also referred to respectively as the *what* and the *why* code. More frequent recurring examples of the *what* include drawing versus part list discrepancies, detailed view changes, and dimensional tolerance changes. Examples of the *why* codes include insufficient analysis, human factors such as errors or oversights, and inadequate training. Approximately 40 of the change/cause codes have been identified and are being tracked for relative occurrence frequency.

Significant accomplishments over a one-year evaluation period include a 25% reduction in drawing versus parts lists discrepancies and an approximate 10% reduction in dimensional or tolerance changes. These reductions are a result of systematic improvements in business systems. For example, checklists have been improved to facilitate the identification of errors during the design review process. Improved technology has provided the capability to generate build parts lists from the digital data sets.

Future plans for the RCA process include enhancements to the RCA system through process simplification, cost reduction, integration of variability reduction tools, improved RCA metrics, and communication of RCA best practices throughout the organization.

## DESIGN RELEASE

### Engineering Source Data Requirements

As the result of increasingly complex aircraft design and proliferation of unique groups of F-16s, LMTAS implemented an Engineering Source Data Requirements (ESDR) Process in 1991 to help personnel more effectively manage engineering data. Included in this formal process was interface design information (text, numeric, schedule or graphic) transmitted between engineering functions to accomplish tasks affecting product performance and schedule not required to be delivered on contract. Also included was specific engineering data requirements agreed upon by the customer and supplier. LMTAS considers the ESDR customer as the employee that needs the data, and the ESDR supplier as the LMTAS employee that must provide the data.

There are nine steps in the ESDR Process.

1. Identify ESDR need.
2. Negotiate schedule and content.
3. Provide the schedule to Engineering Controls.
4. Prepare a transmittal form.
5. Coordinate the ESDR with interface suppliers.

6. Present the ESDR for Internal Design Review.
7. Sign ESDR after revision from the Internal Design Review.
8. Inform Engineering Controls for tracking purposes.
9. Prepare the data and submit it as per the schedule.

Checklists are provided, and monthly reports are generated. The process is scheduled to be expanded in 1995 to extend the existing ESDR by providing outside suppliers with templates for ESDR and facilitating electronic data interchange.

The success of the program has been successful on the first TVI aircraft of the Mid-Life Update Program involving F-16s. After thousands of changes have been processed for the design and installation of over 50 new wiring harnesses, there have been no wiring discrepancies. Also, there have been no significant hydraulic system discrepancies after two years' inactivity.

## 2.3 TEST

### INTEGRATED TEST

#### Avionics Systems Integration

Avionics Systems Integration has undergone significant changes since 1985 at LMTAS. The process has evolved from a series of formal tests verifying each step in the development of the Operational Flight Program to a single, formal signoff at the avionics system level. The system hardware has also been changed from a specific application with generic software to more generic hardware and more mission-specific software.

Implementing the current avionics integration process involved a significant step forward in LMTAS airborne software process and support elements. The number of different development systems required has been reduced from five to three. These three systems are based on common software tools, standard interfaces, and standardized operating systems.

1. *Avionics Simulation Environment (ASE)* is a workstation-based, software-development environment used to develop, integrate, and test Ada object-oriented flight software for the F-16's Modular Mission Computer (MMC). This workstation provides a simulation environment for execution on any of the desktop workstations used by each of the MMC software engineers. An estimated 80% of MMC flight software has been tested using ASE with real-time test stations and simulators before the software's use in the target hardware.

2. The *Core Integration Station (CIS)* uses actual hardware and is the first platform which supports testing of the MMC flight software in its entirety. It can place the MMC in a user-defined, simulated real-time flight environment. The CIS has been designed to allow one user absolute control over the simulation session or shared control between many users.
3. The *Integration Test Station* workstation provides both static and closed-loop dynamic testing capabilities and test of the F-16 Avionics System. It supports design verification, implementation, and compatibility of new or modified avionics using actual subsystem hardware and software. Simulation of real world parameters allows evaluation of scenarios and functions which are either difficult to observe in flight or would pose an extreme risk to the aircraft or the pilot.

Each system utilizes commercial computers with individual versions of the UNIX operating system. They also use generic software, automated software test tools, multi-user and remote features, and common realistic graphical cockpit interface simulations with dynamic aircraft environment models. They are connected on a network for access and data sharing throughout the organization.

Networking and integration of these systems have had a positive effect on the quality of the end product while capital investments, support costs, and direct labor have been significantly reduced. Customer satisfaction and on-time delivery of complete systems continues to support the success of this effort.

### FAILURE REPORTING SYSTEM

#### Logistics Support Analysis Program

LMTAS has effectively used a teaming process for communicating and sharing information necessary to develop a successful LSA program and database. Bringing together all parties who share, need, and/or access specific data has helped eliminate duplication of effort throughout the organization and resulted in a quality product that meets the needs of all the users. A high level of customer involvement throughout the development process, along with periodic reviews, are also incorporated to ensure that the needs of the customer are addressed. Subcontractors are considered an integral part of the LSA team and participate with LMTAS during reviews with the customer. This action has led to a high degree of customer acceptance and satisfaction, resulting in the company being awarded a Blue Contractor Performance Assessment Rating for the past three years. Using internally-developed software and processes has

helped to streamline the performance of the program. The on-line database provides access to any team member and ensures that maximum use is made of all previous LSA analyses.

The LSA management processes include a system for controlled entry, review, and approval of data recorded in the database. Front-end applications and computer routines are designed for a user-friendly interface with other databases and to insure data integrity and configuration control of the information as it is updated and approved for release to the customer.

By applying these practices since 1989, LMTAS has seen a 53% reduction in costs to manage the LSA program. The number of subtasks performed has been reduced from 83 to 21, and the process has been used to identify 558 data elements to be eliminated for each LSA candidate. This has resulted in only 141 significant data elements requiring documentation. The internally-developed LSA/LSAR Guidebook for the F-16 is used by the Air Force as a model for other Government contractors to follow in performing Logistic Support Analysis. Customer affordability, as well as LMTAS efficiency by providing an avenue for early design problem identification and has been increased. The ease of accessibility to all necessary data by every team member makes this program a candidate for many other applications.

## **FAILURE REPORTING SYSTEM**

### **Aerospace Safety Program**

The Aerospace Safety organization at LMTAS is comprised of well-trained and dedicated personnel who strive to improve flight safety in the aerospace industry. The team operates under a company-wide philosophy that states "Significant improvements in product safety only result from continuous Team Effort." Each member of the team is a specialist in individual technical disciplines as well as having broad-based knowledge of complete aircraft systems. In the organization's continual effort to improve flight safety, it examines the reliability of component parts manufactured by LMTAS and any part of the aircraft and aircraft manufacturing process that can contribute to a higher level of safe operation regardless of manufacturer.

This team of experts continually performs safety assessments of field/manufacturing issues. To convey the results of these assessments, it conducts monthly company internal product safety board meetings, and chairs quarterly consolidated flight operations safety council meetings. These meetings include military and company pilots; airfield facilities, air traffic control personnel, safety, field operations, quality assurance, fire/rescue, and flight test personnel; and representatives of any area involved with flight

operations. The purpose of these meetings is to update all personnel on current flight safety issues.

One unique practice is the biweekly "crosstell" conference calls that communicate lessons learned in the F-16 aircraft community. In these biweekly conference calls, company aerospace safety investigators, company safety analysts, Headquarters Air Combat Command representatives, Headquarters Air Force Safety Agency personnel, Ogden Air Logistics Center safety personnel, the F-16 System Program Office safety officer, and Air National Guard readiness center safety representatives discuss safety issues in the F-16 community. This biweekly communication conference keeps all parties current on issues of concern and issues being worked that affect aircraft safety.

As with most aircraft manufacturers, LMTAS participates in a program to provide real-time, in-flight emergency assistance to airborne personnel during an in-flight emergency. This program unites the supervisor of flying who has an airborne emergency with safety and systems experts to assist in finding a solution to the problem. In this program, assistance is provided 24 hours a day through a special "Conference Hotel" phone number.

LMTAS' broad involvement in safety-related processes, safety assessments of field and manufacturing issues, development and engineering review of flight manual procedures, customer and internal safety meetings and teleconferences, and mishap investigation all contribute to safer weapon systems through improved design, procedures, and training.

## **2.4 PRODUCTION**

### **DEFECT CONTROL**

#### **Shop Floor Statistical Process Control**

LMTAS has implemented statistical process control (SPC) on the shop floor in several applications, and the particular methodology in developing SPC on the shop floor is tailored to best fit the process being monitored.

One variability reduction activity identified fastener hole defects as a major problem category. Production of a single F-16 aircraft required the production of over 400,000 holes. Many of these holes are drilled, reamed, and countersunk to close tolerance. The large number of hole defects experienced led to a variability reduction effort in the production area on the shop floor. An initial study determined the need to implement SPC processes to keep the processes under control. It was determined that use of electronic gages and automated SPC would solve the problem; however, the proposed system was too costly. Consequently, a step gage approach was developed which

has proven to be a cost-effective method of controlling the drilling and reaming processes. Step gages are calibrated to allow the nominal size limit to pass through the hole up to a step that is sized to the upper limit. If the step also passes through the hole, then an additional hole is drilled and inspected to check for potential operator error. If the second hole fails, the process requires correction, normally by replacing a drill bit or reamer. Operator instructions include hole check frequency and charting requirements. The charting is accomplished on a simple form that the operator fills in after each hole check.

In the countersink area, electronic gages (Gagetalker III system) are used to check and automatically record data. This is a compact, portable, handheld unit that records data and produces real time SPC displays for the operator. Recorded data can then be transferred from the system cartridge to a mainframe for continual monitoring.

A complete set of step gages for the various hole sizes at each workstation was purchased for approximately \$50K, as opposed to the projected cost of \$750K for the required number of electronic gages. Since the implementation of the system in 1991, hole defects have been virtually eliminated (Figure 2-7). Savings accredited to this system from a single SWBS was calculated to be in excess of \$73K annually.

## COMPUTER-AIDED MANUFACTURING

### Fuel System Simulator

LMTAS has developed a Fuel System Simulator (FSS) as an important tool in conducting aircraft fuel systems testing. Innovative design and fabrication procedures used in the design and building of simulated fuel tanks for the F-22 FSS are helping improve quality and lower program costs.

The FSS facilitates comprehensive systems level testing early in a development program and at a lower cost than conducting testing on a ground or flight test aircraft. The test article includes a shipset of actual aircraft plumbing such as pumps, valves, tubing and instrumentation. This plumbing is installed into a set of full-scale, simulated fuel tanks and monitored and controlled with aircraft processors and software. Test equipment is provide at the FSS to simulate aircraft ground and in-flight environments and other parameters that impact the operation of the fuel system. Equipment is also provided to allow in-flight and ground refuel testing and defueling. This FSS test equipment provides test conditions and allows the aircraft hardware and controls to respond to those conditions in a laboratory environment.

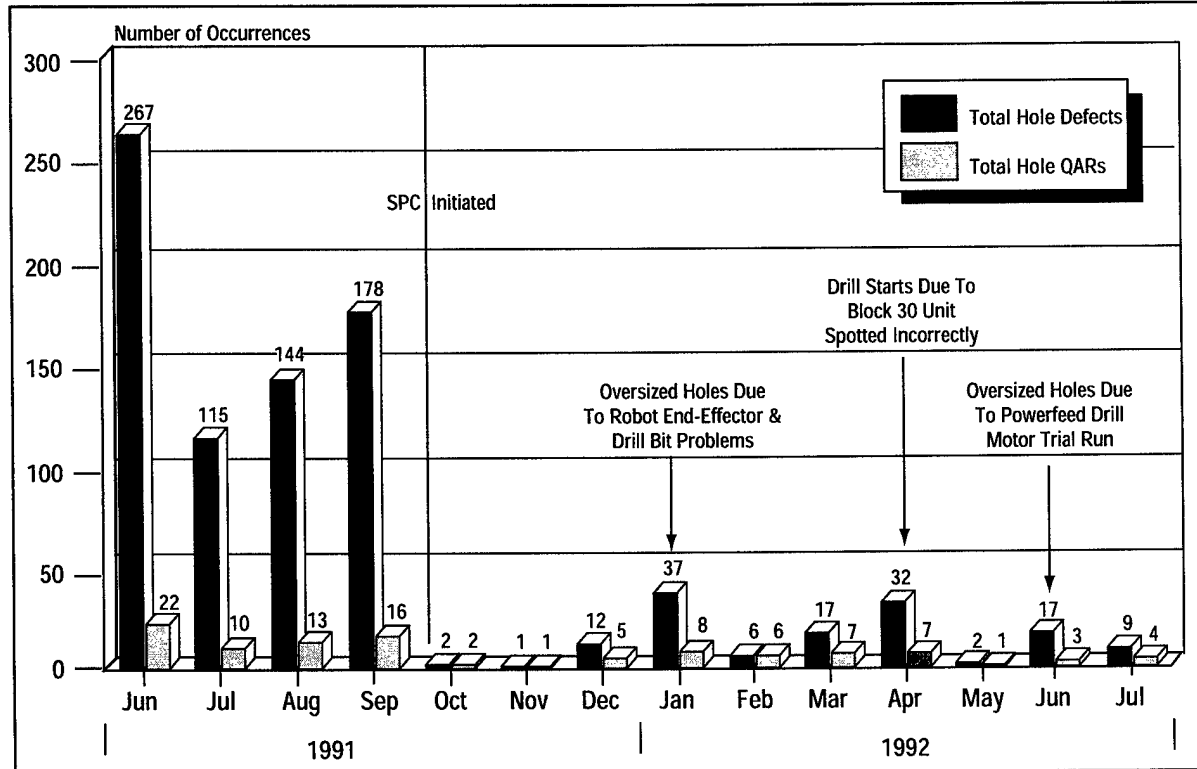


FIGURE 2-7. HORIZONTAL STABILIZER HOLE DEFECTS

Design and fabrication of the integral fuel tanks used in the test setup is an historically time-consuming aspect of providing FSS. The tanks are normally simulations of the actual aircraft structure that constitute the fuel tanks, and are full scale and virtually duplicate aircraft tank volume, geometry, and any internal structural detail that may impact the performance of the fuel system. For the F-22 FSS, LMTAS developed less-manpower, lower-cost procedures to provide these simulated tanks. The procedures include using a two-dimensional simulation of the aircraft structural members making up the integral tanks, using full-scale templates in the fabrication of these structural members, and using a sheet metal roll-forming machine and the structural framework to form contoured, removable skin and inlet duct surfaces. Procedures in welding and sealing have been fine tuned to minimize warpage and leakage of the tank units.

Although the buildup for all tank units required for the F-22 FSS is not complete, improvements have already been realized. The procedures result in design and build of simulated tanks that cost less, provide a higher fidelity simulation of the actual aircraft tanks to facilitate more accurate testing to predict performance, allow adequate access for installing, viewing and maintaining internally-installed aircraft hardware, and are more leak tight.

The more accurate duplication of the aircraft integral tank geometry and structure will also allow better testing of the F-22 on-board inert gas generating subsystem which is relatively new technology incorporated on this aircraft. When completed, the F-22 FSS will be used extensively to verify the performance of the on-board inert gas generating subsystem, as well as the aircraft fuel system.

These design and build procedure improvements provide a capability to perform more comprehensive testing earlier in the program and at a lower cost.

## ENVIRONMENTAL ISSUES

### Hazardous Material Management

In 1984, LMTAS adopted a corporate goal of zero discharge of hazardous waste. This effort was motivated by the high cost of compliance and liabilities with environmental regulations. A proactive formal emissions remediation management program was established using a team approach to achieve the zero discharge goal. Initial baselines were established and plans were developed for hazardous waste elimination and elimination of underground tanks.

By 1987, goals and baselines were expanded to include a multimedia approach to pollution prevention. By 1988, an aggressive plan to reduce hazardous waste by 90% was well underway with 11 completed projects and 11 ongoing projects. The Air Force partnered with the company on facilities and research and development projects. In 1991, a formal Hazardous Material Management Program Office was established which adopted a goal-oriented approach to pollution prevention.

Metrics indicate progress in every major environmental area, and monthly and quarterly measurements are conducted with annual updates. The planning focus is on projects since projects can be tied to very specific goals. To date, more than 50 successful zero discharge projects have been completed. Examples of these projects include:

- Waterborne Primer (1985)
- High Energy Value Waste Segregation (1987)
- Ultrafiltration of Non-recyclable Coolant (1988)
- Mechanical Sealant Removal Process (1989)
- Non-halogenated Substitutes for "Safety Solvent" (1990)
- 47 Closed Systems for Paint Gun Cleaning (1991)
- Aqueous Degreaser (T-529 and T-530) (1992)
- Low Vapor Pressure Cleanup Solvents (1992)
- Reuse Hazardous Waste Drums (1993)
- Spent Lead-Acid Battery Recycling (1994)

Pollution prevention initiatives have saved more than \$25M on hazardous waste disposal alone (Table 2-1). LMTAS was selected from a field of 70 large technology companies to receive the Clean Texas 2000 1995 Governor's Award for Environmental Excellence.

**TABLE 2-1. POLLUTION PREVENTION RESULTS THROUGH 1994**

<u>Result</u>	<u>BaseYear</u>
• 100% Reduction in PCB Devices	1984
• 98% Reduction in TRI Transfers	1987
• 98% Reduction in ODC Use	1987
• 96% Reduction in "EPA 17" Compounds	1988
• 96% Reduction in Effluent Heavy Metal Discharges	1987
• 100% Removal/Replacement of U/G Tanks	1984
• 85% Reduction in Hazardous and Manifested Waste	1984
• 85% Reduction in Reported Air Emissions	1987
• 60% Recycle of Nonhazardous Industrial Solid Waste	N/A
• 42% Reduction in NISW Disposal	1991

*Savings of more than \$25M on Hazardous waste disposal and \$8M on wipe solvent alone!*

LMTAS continues to meet the environmental challenge by working with government and industry groups to help develop national environmental standards such as National Aerospace Standard 411, the National Emission Standards for Hazardous Air Pollutants, and Control Technology Guidelines. The company is also working with the Department of Defense (DoD) Joint Group for Acquisition Pollution Prevention. There are eight current projects and more than a dozen new projects planned. A decade of progress has produced major positive results and a strong team is in place and actively addressing remaining issues.

## 2.5 FACILITIES

### FACTORY IMPROVEMENTS

#### Asset Consolidation

Lean Manufacturing efforts at LMTAS have created an incentive for cost savings in all areas of the Fort Worth facility, and continues to further drive down operating costs through asset consolidation.

LMTAS has deactivated floor space and reduced its manufacturing area by 800,000 square feet, thereby greatly reducing electrical power, heating, and air conditioning expenses to those sections. In addition to the utility cost savings in the manufacturing area, LMTAS has reduced major machinery inventory by 191 pieces (Figure 2-8). Not conducive to the current LMTAS low production rates, the Flexible Machining System and Automatic Guided Vehicle system have been sold, and the income from the equipment sales was recycled back into facility modifications.

Cost improvements have resulted in a 24% improvement in touch labor hours per unit. At the same time, the average monthly F-16 contract deliveries were reduced by 56% and the work force reduced by 37%. These strides in Lean

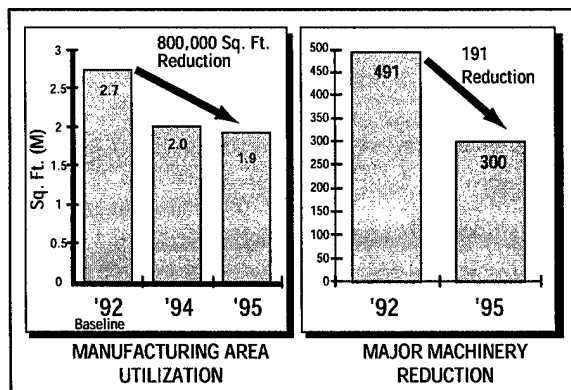


FIGURE 2-8. LMTAS ASSET CONSOLIDATION

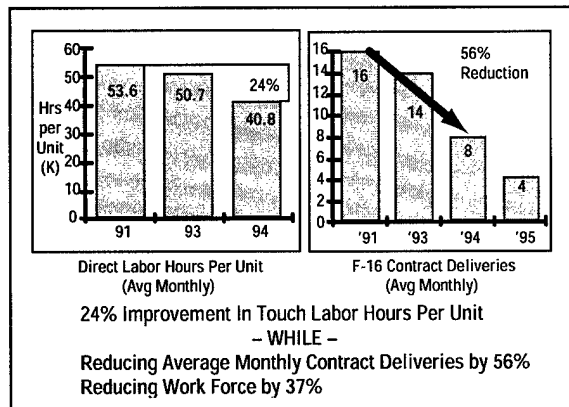


FIGURE 2-9. COST IMPROVEMENT

Manufacturing equate to an overall F-16 cost per unit improvement of 36% from June 1992 to year end 1994 (Figure 2-9).

## 2.6 MANAGEMENT

### MANUFACTURING STRATEGY

#### Integrated Product Development

LMTAS has been applying Integrated Product Development (IPD) since 1991 when an IPD team was established for the Block 50D update to the F-16. This IPD philosophy teams functional disciplines to integrate and concurrently apply processes to produce an effective, efficient product that satisfies a customer's needs, and it requires a strong partnership among contractor, customers, and suppliers.

At LMTAS, Business Area Managers or Program Directors/Managers identify program-unique procedures and processes required for IPD, and prepare and document IPD implementation and management plans. They work with the affected functional organizations to determine team tasks and coordinate team and functional organization plans and schedules to support accomplishment of these tasks. They appoint team leaders and IPD teams, empower team leaders and teams to meet tasking to allocated budgets and schedules required to meet customer requirements and business objectives. The Program Director/Manager, team leaders, and team members monitor accomplishments as they relate to the team plan, and provide reports and status information. Functional Organizations develop departmental plans and procedures for implementing IPD in support of Business Area/program requirements. They assign and empower personnel to meet program requirements, and develop, maintain, and provide technical expertise and functional processes that

support IPD. The IPD team develops a team plan, and the team leader ensures that the plan describes the operational concepts, required resources, and schedules. The Program Manager, team leader, and Functional Organizations set performance objectives, participate in the performance appraisal process, provide recommendations for training and development, and ensure that training is accomplished to achieve IPD goals.

At LMTAS, IPD supports a wide spectrum of programs – from small, one-of-a-kind, short duration programs to large multicompany, multiyear, complex design programs. Thirteen F-16 IPD Programs have been worked since 1990 with ten teams in place.

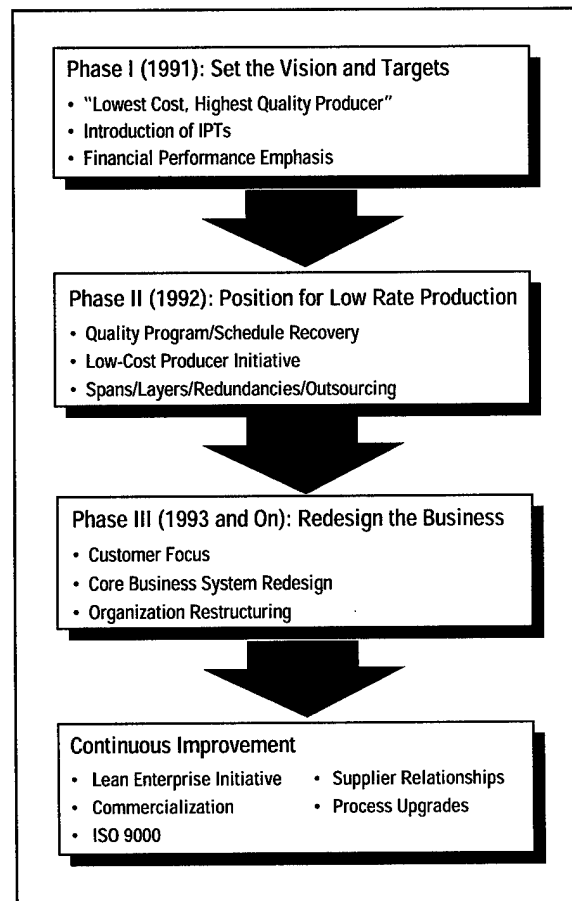
Some important lessons learned were realized from the IPD implementation.

- Centers of excellence must be maintained.
- Organize IPD teams early enough to participate in setting requirements and submitting proposals.
- Customers should be integrated in the IPD Team structure.
- Make suppliers members of the IPD Team as soon as the selection process is complete.
- The functional department should commit to not replace any IPD Team member without consent of the IPD Team Leader.
- IPD Team Members need to maintain a strong link to their home functional department, and know they have a place to return to when the IPD program is completed.
- Keep the number of “Management” positions to a minimum.
- Training for the functional departments should be provided to educate them on the benefits of IPD, interfaces with IPD, and support of IPD.
- Allowing teams to make their own decisions had great potential for simplifying and expediting the development process.
- Team members should be empowered to make necessary decisions in their assignments.
- Serious consideration should be given to collocation for all full-time team members. Collocation should occur at the earliest practical phase of the program.
- Communication is key to any team. Communication should span across all members of the IPD Teams, both union and nonunion.
- Common goals and understanding the goals is essential in IPD.
- Keep the customer informed.
- Suppliers must be treated as team members and informed of issues affecting them.

- DPRO and government procuring agencies must be accepted as a team member and kept informed of meetings, reviews, and decisions.
- Company procedures and policies relative to resource allocations must be better defined to support IPD teaming.
- In-process reviews are crucial to ensure everyone is working to the same ground rules.
- Allow IPD Teams to develop metrics which are meaningful to the team and fulfill functional requirements.
- Do not allow IPD to become the new bureaucracy to replace an old bureaucracy.

### Lean Enterprise Initiative

The LMTAS Lean Enterprise Initiative is a three-phased, major reengineering effort begun in 1991 (Figure 2-10). Prior to this time, as production declined, the company was experiencing quality and schedule difficul-



**FIGURE 2-10. THE WAY WE CHANGED – THREE PHASE PLAN**

ties, prompting LMTAS to reexamine its business. The Lean Enterprise perspective encompasses the whole company and the customer. It focuses on two concepts: *effectiveness* - doing the right things, and *efficiency* - doing things the right way. LMTAS's approach to Lean emphasizes effectiveness first, systematically eradicating areas the company should not be pursuing, and then doing the rest efficiently.

Using total weapon system cost as the integrating metric, the company began eliminating the non-value-added costs and activities from all aspects of its operation. Many operations such as machining, sheet metal fabrication, and most other fabrication operations were outsourced. Only those operations that were considered strategically important were retained and streamlined. The number of employees was reduced from over 30,000 to 12,000. A program cancellation also contributed to the downsizing.

Phase I began in 1991 and set the vision and targets for the change. Phase II - begun in 1992 - positioned the company for low rate production. Phase III, begun in 1993 and now completed, emphasized redesigning the entire business. The company is now oriented around nine core business systems of Customer Value Determination, Business Area Management, Planning and Controlling, New Business, Business Engagement, Product Definition and Design, Product Delivery, Product Support, and Infrastructure.

LMTAS has moved from a traditional fabrication and assembly operation to an assembly and composite fabrication operation with IPT participation by its fabrication suppliers. Weapon system production costs are decreasing dramatically. The per unit cost to the government for the F-16 has been reduced by \$3M, and the company is looking to its proposed commercialization approach as offering the best potential for further reductions.

## Modified Requirements Contracts

LMTAS addressed several pricing concerns with a goal to maintain aircraft unit price as production levels decline. Pricing concerns include uncertainty about future quantities and production rates, low rates and quantities that prohibit competition, and year-to-year instead of multiyear contracts. These problems make it difficult to maintain prices in a declining market. Existing options also offer excellent pricing at nominal-to-high delivery rates but result in premium prices at today's lower rates. These are the issues LMTAS set out to address.

LMTAS turned to its suppliers for help, and the suppliers responded by recommending Modified Requirements Contracting. This contract vehicle is defined in the Federal Acquisition Regulations 17-104.4, but primarily covers low cost commercial products. LMTAS decided to apply this to its more costly defense products.

The following rules have been established with the supplier for Modified Requirements Contracting.

1. There is a maximum five-year contract life.
2. The supplier will purchase material in economic lot sizes.
3. LMTAS will provide a "best estimated quantity" and delivery schedule.
4. Prices will be predicated on an average monthly delivery rate calculation for six-month increments.
5. Prices will be obtained through arms length negotiations.
6. Pricing data is certified up-front and remains unchanged throughout the contract.

This relationship would be maintained with the supplier as long as he delivered on time, applied SPC to produce a quality product, and demonstrated improvements in pricing.

A benefit of this approach for the supplier is the guarantee of business without future competition. The supplier becomes a partner to LMTAS and is provided up-front all known quantities and schedules. Suppliers prefer a 5-year outlook instead of year-to-year. Modified Requirements Contracting also reduces the need for the supplier to have a sales staff for LMTAS and eliminates future estimating within the terms of the contract.

The advantages for LMTAS include establishing a long-term relationship with the supplier and becoming partners in meeting DoD needs. It allows LMTAS to provide quick responses to request for quotes because prices are already established with its suppliers. Request for quotes do not have to be prepared, sent out for quote, and reviewed when they were received. LMTAS has built flexibility into the contracts to adjust to changing market demands. Preestablished limits on quantities and schedules are negotiated into the contract.

By utilizing Modified Requirements Contracting, LMTAS was able to save 6% on its existing MY III contract. It resulted in 22% savings over the options features of its MY III contract. If additional quantities of aircraft are ordered, savings will also be generated on those aircraft.

LMTAS Suppliers have embraced Modified Requirements Contracting, and some have initiated it with their own suppliers. Through persistence and dedication to aggressively perform in a declining defense market, LMTAS has been able to reduce the cost of delivered products even as production rates are drastically declining. This effort is in line with present-day Acquisition Reform Initiatives.

## Factory Layout Planning Techniques

Tactical aircraft, manufacturing such as LMTAS dictates a detailed factory layout Traditional two-dimensional fac-

---

tory layouts describe the size and location of manufacturing and support equipment, but do not easily illustrate other important issues such as capacity, manufacturing sequence, span times, or handling criteria.

To offset the inherent limitations of this two-dimensional factory layout planning, LMTAS produces its facility layout in three-dimensions using Intergraph CAD workstations and AutoMod virtual manufacturing software. A two-dimensional layout is first generated, after which solid models of tooling, parts, and material handling devices are incorporated. Capacity, sequence, span times, and other constraints are then associated with the solid models. The most practical and effective layout solution is then iteratively determined by altering the relative positions of equipment or modifying any of the other model constraints. Considerable planning and data collection must first take place to optimize the most efficient means of producing aircraft.

Control and coordination of the planning process is critical to produce efficient manufacturing layouts. The LMTAS Facilities department has direct control over the budgeting and procurement of capital equipment which increases the department's ability to deliver equipment which will meet a need at the appropriate time. Strong coordination with departments representing employee safety, fire protection, ergonomics, and environmental issues ensures that facility plans meet or exceed applicable regulations and standards.

Since the installation of LMTAS' Intergraph and AutoMod systems, facility engineers have interfaced their workstations with other data systems to facilitate scenario testing, capacity analysis, rate tool analysis, and manpower planning. These considerations can now be fully addressed using a combination of virtual manufacturing tools and planning control/coordination to ultimately provide optimum financial savings.

## MRP II

Examining its internal processes and the downstream effect of other organizations within the company, LMTAS has evolved its MRP II system into a total operations control and accounting system providing data that benefits all of the Operations Division.

LMTAS established a "War Room" to devise an approach that would provide accurate data to effectively make cost and scheduling decisions. This room contained a flow of each step necessary for the MRP II system to plan and control the production of tactical aircraft with its associated costs and the impact that each particular step had on both the preceding and subsequent operations. Not only was this data used to implement the MRP II system, it also allowed LMTAS to streamline the process flow, resulting in reduced cost and schedule.

Contract cost accounting was complex prior to the total utilization of MRP II. Data was transferred to accounting by multiple systems. Prior systems had incomplete work order edits, had little part cost visibility, and contained only estimated WIP values. These data voids generated significant efforts to extract information within the LMTAS accounting community and generated additional costs.

Within the Operations Division, the company had separate systems for Make and Buy parts, including duplicate BOMs, scheduling, planning, and ordering systems. Buy priorities were not linked to the shop floor need dates, thereby resulting in high shortages and higher inventory levels. Inventory levels were assumed by the system.

By evolving the MRP II system into a total product control process, LMTAS has achieved zero accounting errors, eliminating that portion of manufacturing costs. Now a single system is interfaced with accounting, has on-line part cost visibility, complete work order edits, and provides a cost roll-up transfer system that generates audit visibility from lower levels. WIP values using its MRP II system now provide LMTAS actual cost data, thereby supplying accounting with real-time, accurate, detailed cost information.

Internal benefits on the shop floor are a single, integrated system for make-and-buy parts, one BOM, one schedule with one planning and ordering approach. The shop floor can now work to a dispatch list supported by procurement with need dates of purchased parts, and the shop floor also has actual inventory levels netted by the system. Accuracies of 98% or better have been achieved in the BOM, Inventory, and Master Schedule, thereby meeting the goals established within Federal Acquisition Regulations. LMTAS has sustained these accuracies for over two years. These benefits have allowed LMTAS to not only improve customer satisfaction, but also allowed it to reduce costs and enhance schedule performance.

## PERSONNEL REQUIREMENTS

### Ergonomic Tooling/Manufacturing

Since its inception over three years ago, the LMTAS ergonomics initiative has undergone several phases. Originally chartered to reduce cumulative trauma injuries, the Ergonomic Organization reviewed factory processes, and those tasks that surpassed human capabilities were found to directly correlate to cumulative trauma. Working with the factory floor personnel, these identified tasks were changed by either altering the existing processes or by procuring ergonomically designed tools that reduced the cumulative trauma potential.

The Ergonomic Engineering organization takes a proactive role in reducing trauma injuries by working with LMTAS'

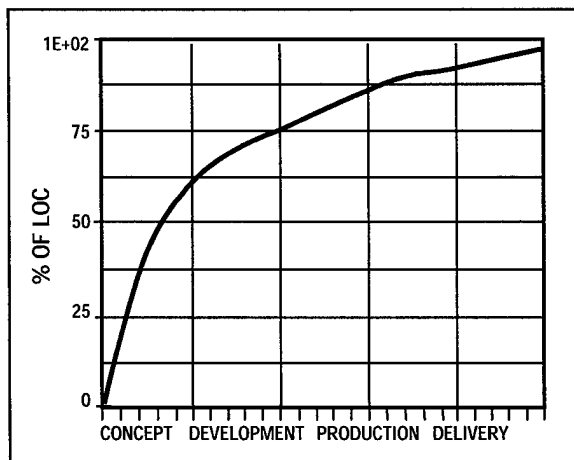
Manufacturing Engineering Organization to identify new tasks that may have the potential of producing injuries. To provide Manufacturing Engineering with a better understanding of potential injury-related processes, LMTAS sent 17 Manufacturing Engineers and Ergonomics Engineers to an in-house Texas Tech University sponsored course on Advanced Ergonomic Engineering design. LMTAS' commitment to ergonomics has been reinforced by the Organization's action of budgeting \$1.05M through 1995.

To assist the local medical community in understanding the processes that the factory floor personnel perform daily, physicians were also invited into the factory. This method not only provided physicians with knowledge of how the injuries occurred, but allowed them to develop a recovery plan for employees. This medical open house benefited everyone involved – the employee by assisting with treatment, the physician by gaining a better understanding of the source of the injury and what portion of the body is affected, and LMTAS by returning the employees to work on an average of two months earlier than the norm.

Through LMTAS' efforts to reduce cumulative trauma injuries and the company's capital investment, several monetary savings were realized in conjunction with employees' health and welfare. Workman's compensation cost-per-100-employees was reduced 20% from 1992 to 1994; the cost per claim was reduced 50%; and the lost work day incidence rate was reduced by 43%. The application of ergonomic principles in the design phase will have the greatest impact on productivity, quality, and safety (Figure 2-11).

LMTAS also determined several lessons learned from its ergonomic effort, including:

- Ergonomic design principles provide the language to design engineering of the human requirements for performing company processes.



**FIGURE 2-11. ACTIONS AFFECTING LIFE CYCLE COSTS**

- If human capabilities are not defined at the beginning (early in the design phase), failures occur in productivity, quality, and safety.
- The development of all processes and design of all workplaces should follow ergonomic design principles.

With ergonomic considerations implemented in the design phase of a project, employee suffering, costs of indemnity payments, product costs and schedule, medical payments, and ultimately the product user (customer) benefit in a win-win situation.

## QUALITY ASSURANCE

### Goal Deployment

LMTAS uses an effective means to communicate company goals and Business Area Manager objectives. These company goals and objectives are defined yearly, documented, displayed throughout the facility, and translated into individual employee objectives. Each employee is aware of what is individually required to ensure company goals are met.

Employee performance ratings and rewards reflect how well employees are meeting the objectives, and no quotas exist on any level of performance rating. Within each performance rating level and job type, employees are ranked and rewarded based on that ranking. Metrics are established for monitoring the progress toward meeting the goals and objectives. Rewards can be either financial or progress on a career path.

Rewards are designed to motivate employees and to recognize outstanding performance that improves LMTAS' effectiveness. Financial rewards include merit compensation, performance improvement plans, or special meritorious awards. The yearly merit compensation is based on an individual's performance rating and ranking on achieving their goals and objectives. The special meritorious award is given for a special effort or contribution to a job or task that exceeds normal job requirements. The award is accorded to either hourly or salaried employees and can be given to either a group or an individual. The performance improvement plan award recognizes outstanding performance by a salaried employee for performance substantially beyond that which is expected of the employee's position. The award can be either an individual or team award. Career path rewards can be increasing responsibilities, special assignments, or promotions. The increased responsibility results from an employee exceeding assigned goals/objectives and can be as reassignment to a task that adds responsibilities. The increased responsibility can involve expanded difficulty of tasks, coordination with higher levels of management, or a leadership role. Special assignments involve

placement of an employee in a special role as a reward for excellent performance. Although financial rewards are part of promotions, the expanded responsibilities and the opportunity to move upward in the organization enhance an individual's career path. Promotions are the result of an employee consistently exceeding performance standards and the goals and objectives they are assigned.

Significant improvement in metrics have occurred from 1991 to 1994 (Figure 2-12). The requests-for-engineering-actions backlog decreased from 950 items with a 12-day turnaround to 53 items with a 2-day turnaround. The on-time scheduled events' rate has improved from 60% to 96.8%. The manufacturing support has decreased by a 32% reduction. These improvements are the result of goals and objectives being clearly defined and communicated to all employees.

### Product Definition and Design Metrics

Extensive use of metrics within the Product Definition and Design (PD&D) Business System at LMTAS provides

a management and tracking system to measure performance against goals and objectives. Management by metrics is encouraged, and these metrics are prominently displayed in the work areas. In support of the LMTAS goal deployment philosophy, the PD&D work force self-determines performance metrics to align with company objectives.

Using indices represents one method of rapidly managing diverse measures. For example, at the Research and Engineering level, two major indices are used – the Continuous Improvement Index (Figure 2-13) and the Progress Maintenance Index. These indices include weighted averages of selected financial and quality metrics. Criteria for selecting individual indicators for the index include:

- Is the measure directly linked to customer satisfaction?
- Is the metric objective and independently verifiable?
- Is the metric understandable?
- Is the metric sensitive enough to provide timely indications of performance changes?
- Does the metric not adversely impact the process being measured?

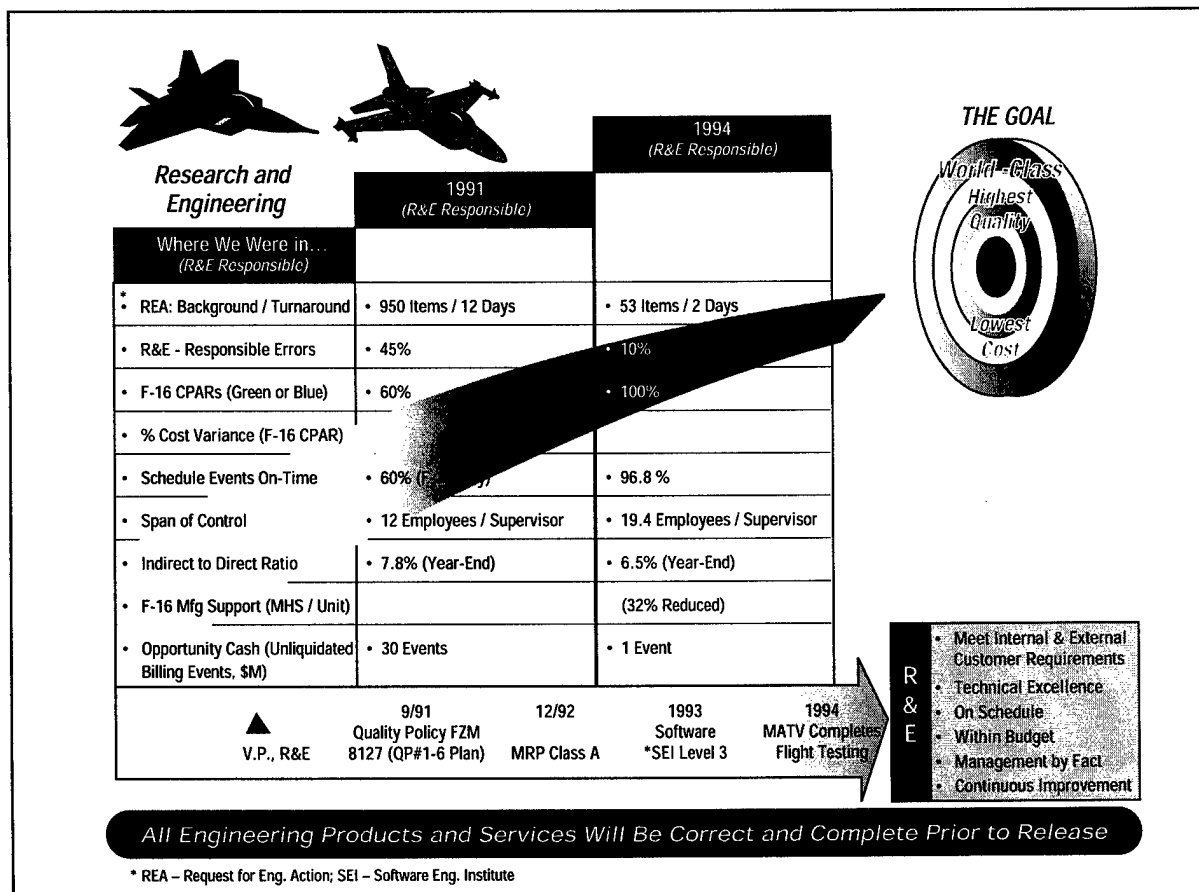


FIGURE 2-12. DEFINING OUR FUTURE

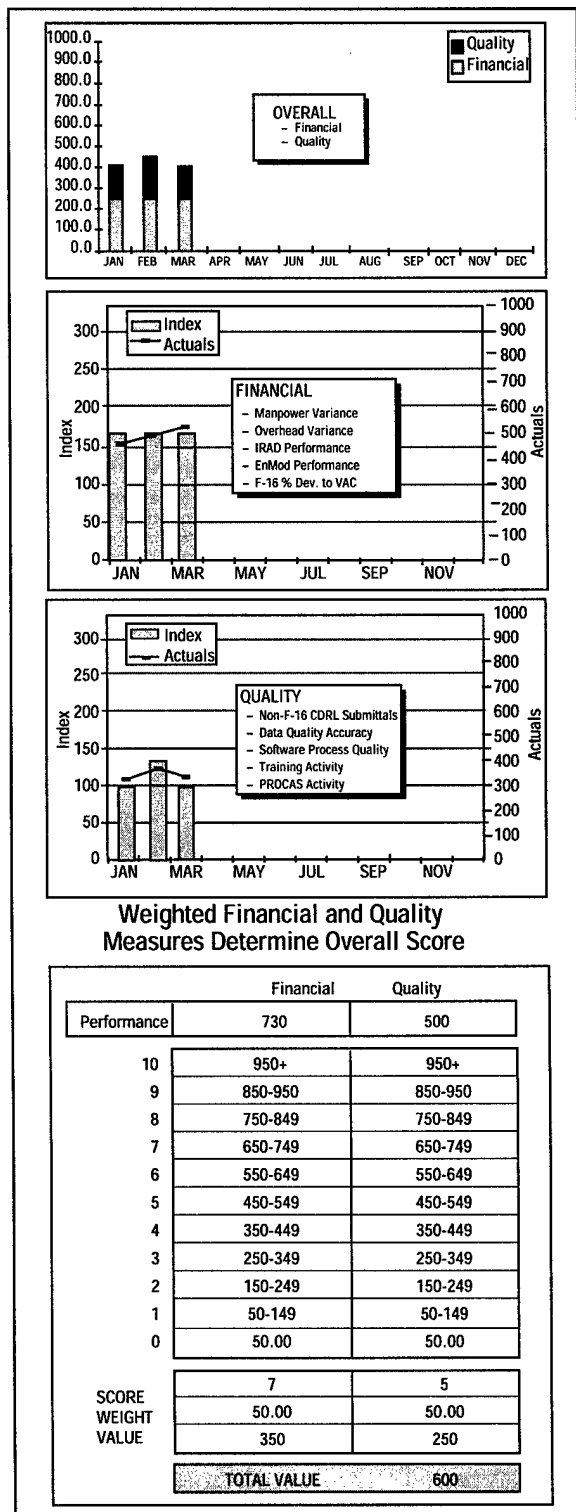


FIGURE 2-13. IMPROVEMENT INDEX STRUCTURE

- Does tracking the metric require reasonable resource expenditures?

Indices are updated monthly, and a movement of two or more points on individual indicators is highlighted for management. An index provides a relative, summary-level measure of performance, provides greater credibility than individual measures but can be tailored for the appropriate objective. Group level metrics defined and maintained by the individual groups are based on common measures within PD&D and group-unique measures. Each group is responsible for improvement actions based on metrics.

### Internal Review Process

The Internal Review Process (IRP) at LMTAS is a functional and/or cross-functional review activity that seeks to establish compliance of a product with its corresponding set of product requirements. By using comprehensive and timely internal reviews, the IRP ensures PD&D products are correct and complete before release.

Formally instituted within PD&D in 1994, the IRP begins with the requirements/concept phase and continues until the product has been produced and proven. Participants in the IRP include PD&D, Manufacturing, Quality, Logistics, Material, and DPRO. Elements of an internal review are the agenda, checklists, minutes, and action items. The agenda announces the review, articulates the review plan, and establishes exit criteria. Checklists identify potential problem areas and are developed, maintained, and improved by individuals/groups. These checklists are tailored to the needs of individuals/groups, and are used with the agenda to plan review questions. Minutes were produced to document review decisions and agreements, highlight unresolved issues, include checklist summaries, and include plans for future reviews. The checklist summaries provide excellent means to track lessons learned and support of root cause analysis. The action items are assigned to review participants and are tracked to closure.

Internal reviews ensure that requirements are properly addressed since the product and/or process is compared with the requirements. Omissions are discovered, extras are identified, and misunderstandings are resolved. This effort in turn helps LMTAS improve the product by reducing errors, while positively affecting schedules and cost. Another major benefit is the customer's satisfaction that comes when the customer is delivered a product as it was requested.

### Supplier Relations

LMTAS has established an aggressive and comprehensive Supplier Relations Program to develop and continuously

improve a strong supplier base that provides low cost, high quality products that are delivered on time. The Supplier Relations Program is one of the five major areas of Lean Manufacturing initiatives being addressed by LMTAS. Many companies approach improving supplier performance through fragmented and isolated supplier improvement initiatives. However, the LMTAS strategy has been a centrally-coordinated effort that addresses all aspects of the supplier base improvements from objective metrics to improved communications to cost/quality/schedule to long-term relationships with best value contracts (Figure 2-14).

Challenged by the declining defense aerospace market and the increasing competition for the remaining markets, LMTAS reexamined its overall strategy on where to apply innovative management techniques and business practices to achieve the corporate objectives of low cost/high quality, on-time products. Lean manufacturing initiatives identified five major areas for improvement including the development process, customer relations, management/organization, factory operations, and supplier relations. The focus on supplier relations was influenced

because purchased material is a high cost driver for LMTAS products, accounting for more than 50% of the total cost. The second challenge then was placed on the Procurement Division to develop and carry out a strategy to improve supplier relationships through "best value" in a timely manner that would be effective to the LMTAS business.

The *foundation* of the Supplier Relations effort is the ability to generate objective metrics. The *framework* of Supplier Relations consists of core programs that include Supplier Integrated Product Development, Supplier Performance Evaluation and Review, SPC, MRP II, and Supplier Certification. Within this framework are the activities and programs that the Procurement Division has implemented and/or is developing to improve supplier communications; affect cost, quality, and schedule; and establish a certified supplier base. The infrastructure for communicating metrics to the supplier has been accomplished through the Supplier Rating System process, the Supplier Integrated Product Development process, and the MRP II system.

A Supplier Performance Evaluation and Review (SPEAR) process was developed to communicate problem recognition

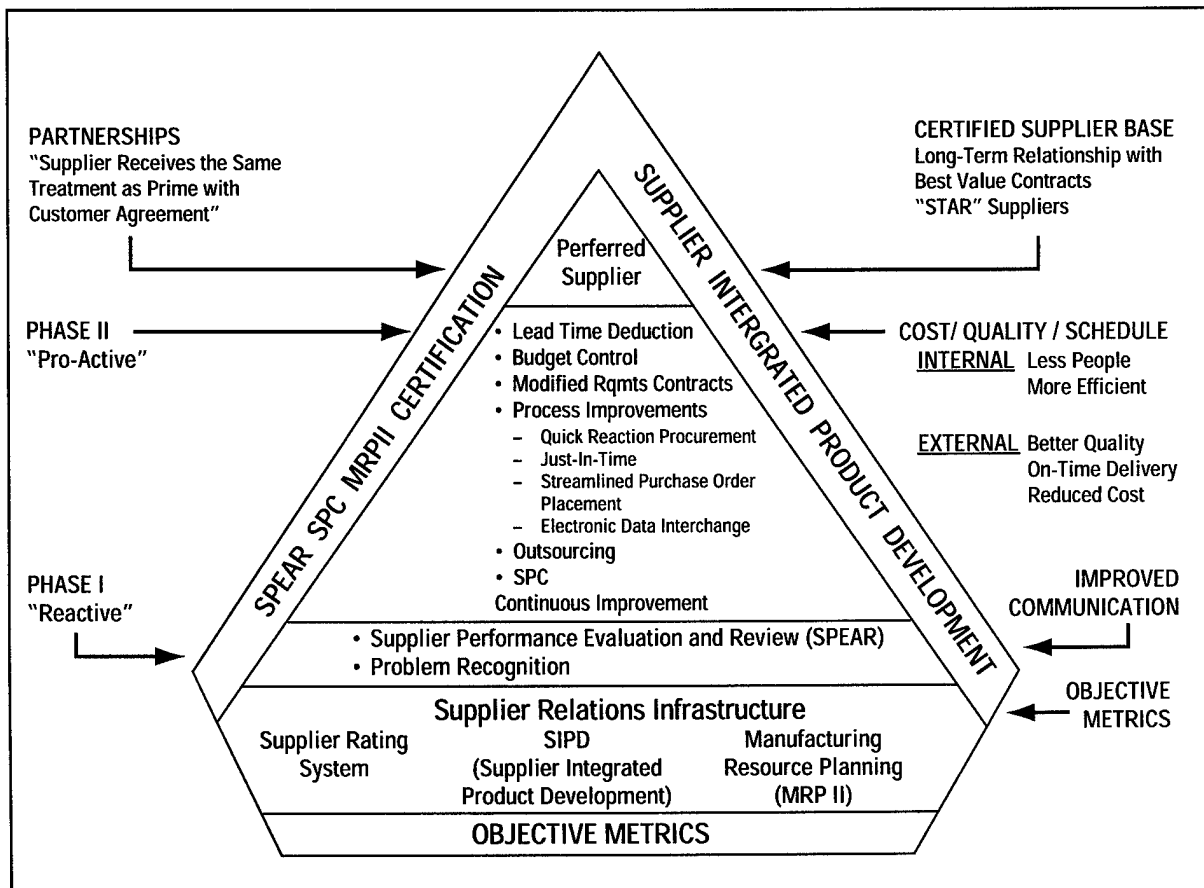


FIGURE 2-14. SUPPLIER RELATIONSHIPS THROUGH VALUE

---

and corrective action with the supplier. To affect the cost/quality/schedule both internally and externally, the Procurement Division applied innovative management techniques and business practices that included specific programs such as SPC, Outsourcing, Modified Requirements Contracting, Budget Control, Lead Time Reduction, and Process Improvements. The Process Improvement efforts included programs such as Quick Reaction Procurement, Just-In-Time, On-Call, Streamlined Purchase Order Placement, and Electronic Data Interchange. These programs ranged from newly developed to the adaptation of existing practices that has been key to their efficient and timely integration to establish the "STAR" suppliers.

The impact of the Supplier Relations effort has contributed to all aspects of the LMTAS business and the other four Lean Manufacturing initiatives. Per unit cost of deliverables has been reduced although total volumes are declining, and 98.0% of all schedules are being met while maintaining high levels of performance.

### Supplier Rating System

Based on the results of a study made by a team of Procurement and Supplier Surveillance Assurance personnel in July 1994, LMTAS incorporated changes to its existing supplier rating system. These changes were designed to simplify the system and make it easier for Lockheed's customers and suppliers to understand the process.

The previous system for supplier rating was based on separate ratings for quality cost, and percent rejections. This data was used to construct a relative rating scale of 1 to 5. The suppliers were forced into a normal distribution such that the top 8% were rated 1, the next 17% rated 2, and so forth. This system did not provide adequate absolute performance information and consequently, caused confusion for the suppliers.

The new system is based on how well the supplier is performing compared with its own abilities. Two basic parameters are used to measure the supplier's performance, purchase order delivery schedule and quality performance. Purchase order deliveries are tracked and status reports are generated monthly. To remain acceptable, the supplier must maintain a concurrence level of 96% or higher. Quality performance is measured against percent acceptance and cost of quality. Percent acceptance at source inspection must be 98% or higher while Lockheed's quality cost must be \$2.5K or below. Suppliers are placed on a Deferred Status if they do not meet these criteria after being notified of deficiencies and fail to carry out satisfactory corrective action. During this time, corrective action is monitored and special approval must be obtained for all purchase order awards on existing or new part numbers. If

the supplier fails again to implement satisfactory corrective action, it is placed on Approval Withdrawn Status. The supplier is not used for follow-on procurements, and special approval is required for purchase order awards on all part numbers. The supplier performance data used in determining these parameters is made available to procurement by Supplier Surveillance Assurance, International Surveillance Assurance, Software Quality Assurance, Engineering Data Quality Assurance, and Technical Publication Quality Assurance. The data is based on a moving six-month history and is automatically calculated and reported every quarter.

The Supplier Performance Metric (SPM) is used to incorporate the quality performance parameters into a single unit of measure. The SPM is calculated as the total cost divided by the percent acceptance. Suppliers with a value near 1.0 are rated as excellent and can be considered as candidates for the STAR Program. Values exceeding 1.1 are rated as unsatisfactory and are recommended for placement in the SPEAR Program.

The improved system for supplier rating has accomplished LMTAS' initial goals of simplifying the overall rating system. Additionally, customers and suppliers find it more informative and easier to understand than the previous system.

### Supplier Statistical Process Control

The goal of the LMTAS Supplier SPC program is to ensure that the company's suppliers use SPC techniques to reduce cost and improve product quality. In March 1988, the Variability Reduction Committee formed a supplier SPC subcommittee, and a supplier conference for SPC was held the same month. The two-year voluntary program that followed met with very limited success. Therefore, in August 1990 LMTAS decided to make SPC a purchase order requirement that would go into effect in January 1991.

A Supplier SPC Team was formed to work with the supplier base for certification, with a secondary goal of reducing the number of suppliers from 1784 to a more manageable number. In November 1990 the Supplier SPC purchase order requirement was created. This requirement document was called "Appendix Y" and it became effective as a contract requirement in January 1991 with supplier certification due by June 1992. In March 1991 all suppliers who had not submitted an SPC implementation plan were locked out from all procurements resulting in a gradual reduction in the supplier base from 1784 to 600 vendors.

Appendix Y establishes the framework necessary for a supplier to set up SPC and obtain certification. It is not a "how-to" document. For SPC system approval a supplier must define their SPC implementation procedures and

develop a milestone plan. SPC certification requires a system certification with quarterly reports and a product certification with an annual re-audit. The LMTAS supplier SPC team must verify that the supplier has management involvement and participation, has responsibility established, has the SPC system proceduralized, has knowledge of SPC at all levels, applies SPC techniques effectively, and is working to improve processes and products. While the team does not dictate how SPC techniques are used, they are charged with assuring that the supplier's SPC system is effective. Supplier SPC system level approval requires a facility wide implementation of SPC on all key processes and a system that focuses on processes rather than being part-number specific, emphasizes monitoring capability, and pursues continuous improvement. For product level certification, the supplier must demonstrate and maintain minimum capability for all key characteristics of the certified part or family of parts. The control characteristics and key characteristics must be in control and can show a  $C_{pk}$  of 1.33 or 99.9%.

LMTAS Supplier SPC administrative requirements and procedures in addition to Appendix Y include a Material

Department Instruction and a Buyers' SPC Handbook. Under Appendix "Y" a requirements matrix by supplier category outlines the requirements and identifies applicable paragraphs by supplier category (Figure 2-15). The purpose of the MCI is to delineate the responsibility of the Buyer, Supervision, and the SPC Team in administering the Supplier SPS Purchase Order requirement (Appendix Y) and for tracking supplier conformance.

The Buyers' Handbook is published to help the Buyer administer supplier SPC purchase order requirements, and it contains a copy of the requirements, procedures, work instructions, Memoranda of Understanding, directives, and sample forms, letters, and charts.

Implementation of this system has reduced the supplier base to approximately 600, raised the purchased material acceptance rate from suppliers (yield to stock) to 99.9%, transitioned acceptance inspection from LMTAS to the supplier facility, raised purchase order delivery concurrence to 98%, and reduced supplier cost while being in a low rate production environment. It should be noted that contracts are not rebid for those suppliers demonstrating consistently high quality and effective cost control.

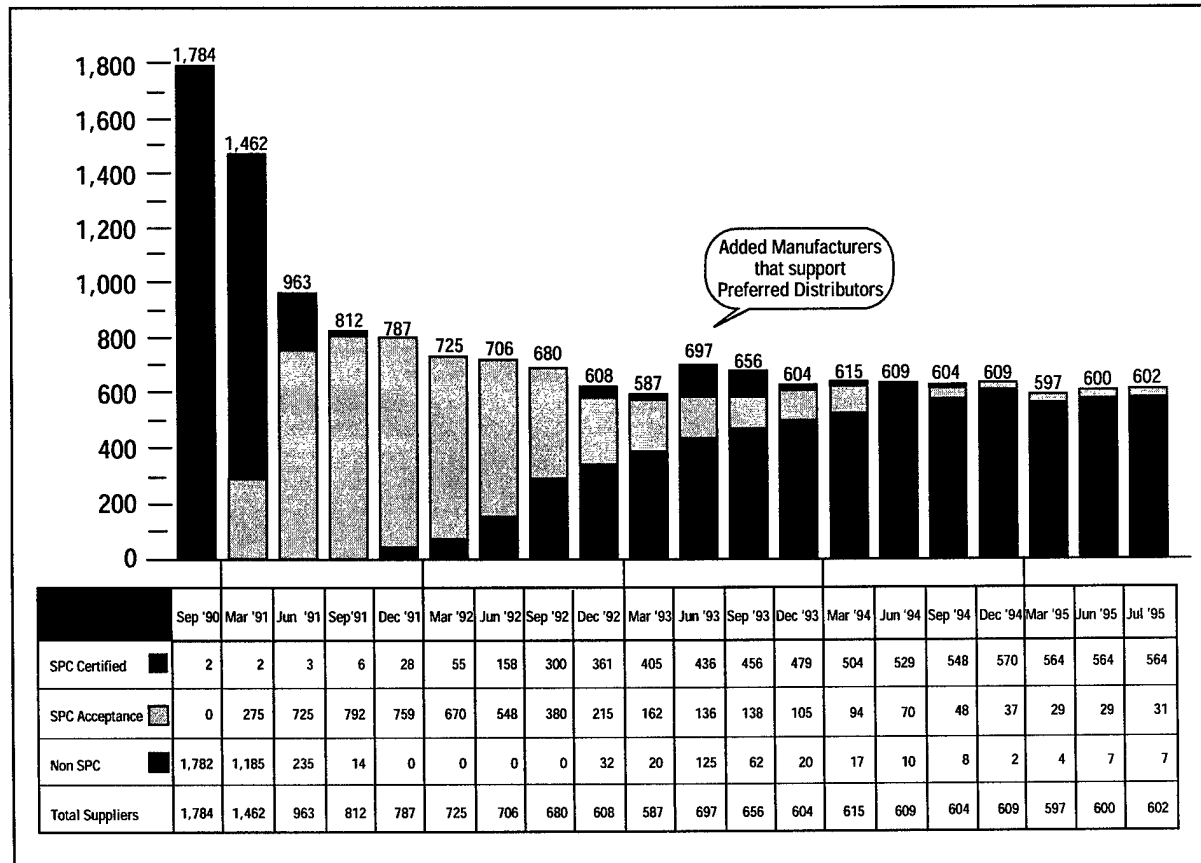


FIGURE 2-15. SPC SUPPLIER COMMITMENT STATUS FOR PRODUCTION SUPPLIER

---

## Supplier Performance Evaluation and Review Program

LMTAS has established a new program – referred to as the SPEAR Program – to monitor the performance of those suppliers whose performance falls below required levels. This effort highlights cooperation between LMTAS and the affected suppliers so satisfactory performance can be restored and long term relationships maintained.

LMTAS has established minimal acceptable quality and schedule performance criteria that its suppliers must meet. For quality, a supplier must maintain less than 2% rejections over each quarter and limit nonconformance costs to less than \$2.5K. For a schedule, the supplier must maintain a concurrence level of 96% or higher. When these levels fall below the specified limits, the supplier becomes a candidate for the SPEAR Program.

At that time, the supplier must develop a corrective action plan that outlines actions it determines necessary to correct the deficiencies. Lockheed uses this plan to monitor progress of the resulting corrective actions. Provisions also exist in the program to allow both the supplier and LMTAS to work concurrently to solve disagreements and provide mutual resolution to the problems. Therefore, a reactive problem solving approach is used to correct the deficiencies instead of traditional methods that impose penalties when the supplier's performance falters. If, however, acceptable improvement is not obtained, the supplier is transferred to an Approval/Withdrawn Status and made ineligible for new business.

The SPEAR Program promotes long-term cooperative relationships between LMTAS and its suppliers. It gives LMTAS rapid problem identification and resolution and provides an effective method for eliminating non-performing suppliers. The supplier not only is given the opportunity to remain a viable source to Lockheed through corrective action, but also benefits by the quality and schedule improvements made to its products. To date, 478 suppliers have been identified as SPEAR Program candidates with 106 of those placed in the program. Through active corrective action efforts, 83 of the 106 suppliers have been reinstated, with only 7 removed from new business eligibility.

### F-22 Variability Reduction

LMTAS has established a Variability Reduction (VR) program to meet a contractual requirement of the F-22 program. Under the contract, the VR program and related activities are designated as award fee criteria. There are several defined objectives under the contract which includes: to reduce variation of key characteristics; estimate the impact of process variations on key characteristics; verify that key characteristics requirements are com-

patible with the manufacturing process; identify producibility studies for improving quality, increasing integrity and/or reducing production cost; characterize key manufacturing processes using statistical data; reduce scrap, rework and repair; and, reduce reliance on end item inspection.

A seven-step approach has been developed to meet these objectives. This approach begins by identifying key characteristics. A key characteristic is a feature of a material, part, or assembly critical to the fit, performance, or integrity of the product. The VR team used Design of Experiments and Quality Function Deployment tools in a structured approach to systematically break down top-level requirements into lower level components. These lower level requirements are examined to decide key characteristics that are then associated with related individual control characteristics. The second step in the program is to correlate the identified key characteristics to processes. This is followed by prioritizing and selecting firm key characteristics. Step 4 involves developing Variability Reduction Instructions for each of the selected key characteristics. These instructions include product definition, key characteristic description, manufacturing approach, data collection, tooling approach, process assessment, process analysis, and product feedback. Once developed, the Variability Reduction Instructions are incorporated into the Product Development and Definition build-to package. Step 6 involves actual process control of the key characteristics, and the final step provides feedback reporting for monitoring and continuous improvement activities.

The VR team on the F-22 has identified 2561 product key characteristics. These are part-number driven and equate to the 678 processes/part families that led to the development of 126 Variability Reduction Instructions. Lessons learned during this process include the need to incorporate VR into normal engineering requirements to help early identification of key characteristics. This would ease earlier usage of Design of Experiment and Quality Function Deployment tools. Cross functional VR teams greatly simplified the implementation of VR, the use of quality tools was widely accepted by the IPT, and active coordination among the three primes ensured a common approach.

No award fee on the F-22 has been lost since the implementation of the VR program. An example of other benefits can be shown by looking at improvement in the NC trim operation of composite doors, skins, webs and floors. Since this system has been in place, the  $C_{pk}$  for this operation has improved to its current level of 1.2 or about 99.9%.

### On Call and Just-In-Time

The On-Call and Just-In-Time programs will help reduce procurement dollars committed by LMTAS to maintaining inventories and to affect the goal of reducing inventories to

zero levels. The On-Call program was started five years ago and applies to more than 240 contracts covering 6000 line items. The Just-in-Time program was started three years ago and applies to two large contracts covering 1000 line items. Both programs are initiatives under the LMTAS Supplier Relations Program.

Maintaining inventories at some designated level to insure that materials are available when and where they are needed is a costly trade-off compared with the value added to the product. Costs associated with maintaining inventories are often overlooked in assessing the total acquisition costs of a product. However, they are manifested in floor space, utility costs, recordkeeping chores, storage and retrieval needs, security, capital equipment, facilities, and personnel resources. Most importantly, the money invested in the materials is frozen. The On-Call and Just-In-Time programs provide proven procurement techniques refined by LMTAS for eliminating, or at least minimizing, inventory.

The On-Call program is a multiyear procurement of a specific material or like materials such as office supplies or safety equipment, to be delivered only on "call" from designated personnel. This type of contract specifies delivery time and frequency for materials as required by the user. The Just-In-Time program is similar to On-Call except in the multiple users with different requirements and large "group" of like materials, such as perishable tools and industrial supplies. A key element of both programs is the performance of the supplier, a result of LMTAS successfully developing its outstanding supplier relationships under the Supplier Relations Program.

Although non-production items have been the target for both programs until now, production items are currently established in the programs. As the result of applying On-Call and Just-in-Time, excess inventory has been consolidated and nearly eliminated, and the total acquisition costs have been significantly impacted. At the same time, delivery schedules and quality have also continued to improve through this and other LMTAS initiatives. Close to \$1M in material investment savings have been documented since the programs have been initiated. Over 100 personnel resources required to store, retrieve, secure, and keep records have been eliminated.

## Continuous Performance Improvement

Senior Research and Engineering management at LMTAS initiated continuous performance improvement efforts in 1991 which were begun with the QP#1 which states that "All engineering products and services will be correct and complete prior to release." Since its inception, a series of milestone events has been achieved leading to the development of a PD&D Continuous

Performance Improvement Plan in 1995. Significant events are as follows.

- 1991 - Issuance of QP#1
- 1992 - MRP Class A rating - Independent outside review
- 1993 - Velocity Improving assessment by outside consultant.
  - Process Oriented Contract Administration Services Memorandum of Understanding
  - Top Southern District Performer
  - SEI Level III rating
- 1994 - Employee "King For A Day" Program
  - MATV Flight Test Success
  - Named as Reinvention Lab
- 1995 - Development of PD&D Continuous Performance Improvement Plan

Under the direction of the Vice President for Research and Engineering, a multifaceted, structured approach has been developed to achieve the QP#1 objective. This approach is based on a four-quadrant plan to capture, plan, facilitate, and implement continuous improvement throughout the organization. Critical processes have been identified as critical to this deployment, including an engineering source data requirements process, internal review process, product proof and prototype validation process, integrated product development, a software engineering process, root cause analysis, and variability reduction process.

Analysis of cost drivers in each of these processes by internal and external review has been accomplished through various means. This analysis provides the capture portion of the plan and is a continuous process. Objectives are identified at the top management level and flowed down through all levels within the organization. Metrics are established to monitor progress toward those objectives. These metrics are charted at each organizational level and rolled up into an Improvement Index Structure for reporting to senior management. This index reports on key indicators through weighted financial and quality measures that determine the overall score. These key indicators have shown a positive trend since the program inception in 1991.

The 1995 Product Definition and Design Continuous Performance Improvement Plan defines the Critical Processes and Initiatives for 1995. It was developed to reset the continuous improvement bar based on the 1991-1994 achievements. The plan is a multivolume document includ-

---

ing PD&D Support of Company-wide Initiatives, PD&D Initiatives, Objective Evidence of Progress, and Demonstrate Strength with Speed sections. Sections include critical process descriptions, identification of responsible individuals, and establishment of key indicators to monitor improvements.

## **DESIGN/MILESTONE REVIEW PLANNING**

### **Supplier Integrated Product Development**

Supplier participation in the source selection process employed by LMTAS is an integral factor to achieving a low risk, cost effective, and affordable program. The Supplier IPD Source Selection Process provides a well-defined set of program requirements as well as the basis for proposal preparation. It also supports the philosophy that a proposal can be prepared with complete understanding of and agreement with the requirements.

Before Supplier IPD, the source selection process did an inadequate job of defining what the customer wanted, what the product team could provide, and did not permit the supplier to have a clear understanding of the Request for Proposal (RFP). Key deficiencies existing in the previous source selection process included the incapability to rate the differences between bidders and the inability to analyze risk. With Supplier IPD, the supplier becomes a member of the product team whose membership includes all groups with a stake in the program's outcome. The supplier then has the opportunity to participate in defining program requirements; obtain customer ideas; evaluate alternatives; review the technical approach; conduct risk assessment; identify customer needs; review contract type; and endorse schedules and quantities. The process helps the user determine if a supplier is qualified to receive an RFP. Additionally, the process allows potential sources to review previous input and to influence final RFP requirements.

The final RFP provides a well-defined set of program requirements that is thoroughly understood, mutually agreed to, meets customer needs, is cost effective, and provides a

low risk approach. It provides the basis for proposal preparation to do it right the first time, is more cost effective with no best and final offer anticipated, reduces evaluation time, provides a complete understanding of any cost/schedule risk to the program, and defines and agrees to schedules. The proposal can be prepared with complete understanding of and agreement with the requirements.

## **MAKE OR BUY DECISIONS**

### **Outsourcing of Non-Core Processes**

In response to the decline in budgeted dollars allocated for defense programs, LMTAS initiated cost and risk reduction by outsourcing nonstrategic tasks such as machining, sheet metal part fabrication, and electrical fabrication. This outsourcing process provides quality products at a reduced cost. During this time of rightsizing, LMTAS reduced its work force drastically. This reduction influenced both hourly and management personnel. While hourly employees declined by 53% and management declined by 49%, the company was able – through outsourcing – to realize a 94% reduction in behind-schedule hours and realize a 100% compliance of delivery on kits and spares with no delinquencies.

With outsourcing, a reduction in support operations was also realized without significant impact on customer compliance. While economic and customer requirements dictated rightsizing, LMTAS was able to reduce support personnel in those disciplines deemed strategic and not outsourced. This effort netted a reduction in the ratio of support personnel to direct labor from 2.1:1 to 0.7:1. Realizing the risks associated with outsourcing, LMTAS met with its vendors and negotiated their membership on internal Integrated Product Teams, thereby securing buy-in and a sense of ownership of the company's methodology. This vendor-and-internal teaming has resulted not only in filling a void but has produced a 100% reduction in spares delinquencies, a 99.9% reduction in part shortages, and a 99.9% reduction in hours of work performed out of sequence because of shortages.

# SECTION 3

## INFORMATION

---

### 3.1 FUNDING

#### MONEY PHASING

##### MRP Purchasing Management System

The MRP II system at LMTAS is an electronic closed-loop system that maintains cost accountability for the material flow process. It efficiently provides the correct quantity of required materials at the needed time and place, and maintains accurate records of all material flow information. The system includes Master Scheduling, Bills of Material, Inventory Control, Shop-to-Floor Control, and Purchasing Management. Accuracy for the data maintained by this system is 99% to 100% for Master Scheduling, 99% for Bills of Material, and 98% to 99% for Inventory Control.

The Purchasing Management System which resides in the MRP II system is a user-friendly, menu-driven system used to track material purchases from the initial creation of the purchase order requisition to acceptance of the material in receiving and stock. It enables the planner to create purchase order requisitions according to system specifications, use standard text and the purchase order request to build the Request for Offer, and automatically create the purchase order from data on the Request for Offer. It also is a large repository for information related to the procurement process. Work load reports, purchase order histories, and dock-to-stock transactions are created and monitored using this system. Additionally, the system maintains an on-line vendor information resource providing such information as approval levels, certifications, delivery performance, and status of open purchase orders for each vendor.

The Purchasing Management System is a valuable asset to the MRP II System. It has reduced the levels in inventory, reduced the occurrence of shortages, promoted on-time supplier delivery schedules, induced improved pricing, shortened lead times, and provided improvement in product quality. This proven track record, combined with the accuracy shown within the other subcomponents in the MRP II system, has provided a high-confidence-level material flow tracking/cost accountability system for Lockheed.

##### Automated Budget Control System

LMTAS has established an automated Budget Control System to increase the speed and efficiency with which high-volume procurements are initiated and approved. This

new system, in use since 1994, has been effective not only in streamlining the purchase order process but also in increasing accountability for those purchases made.

The goal of the new system is to maintain control of all procurements at the part number level. When purchase orders are placed and entered into the system, the estimated price is compared with preestablished target costs originally made from customer negotiations. Cost data for the purchase order is accessed and prorated to the individual part number to obtain unit cost data. This value is then used to classify the item as a high dollar or low dollar procurement. If the purchase order is classified as a high-dollar procurement (more than \$500), acceptance is granted if the unit cost falls under the preset Budget Bank Target quantities. If the purchase order is classified as a low-dollar procurement (less than \$500), acceptance is granted if the unit cost falls under the modified average unit cost. Currently, the modified average unit cost is calculated as 130% of the average unit cost.

Once determined to the preestablished target costs, the purchase order is automatically accepted without the buyer's concurrence. However, if the purchase order is rejected, it is forwarded to the maintenance budget control analyst, who determines the best course of action. Usually, if acceptance of the purchase order must be allowed, the buyer will change the quantity and corresponding unit price or the purchase order rejection will be overridden.

There have been several benefits gained by introduction of the new automated Budget Control System. Budget issues are resolved much more quickly, substantially reducing procurement cycle time. Predetermined target data has aided buyer negotiations with the supplier and allows for quick identification of potential procurements exceeding budget limitations. Additionally, Procurement's awareness of controls provides for greater accountability of quantities ordered.

### 3.2 DESIGN

#### DESIGN POLICY

##### Process Quality Policies

LMTAS addressed management and production difficulties by implementing new plans, instituting continuous improvement, and establishing process quality policies. Its successful efforts have included establishing IPTs and new

management positions, instilling manufacturing discipline, and applying Process Quality Policies. These actions have contributed to a significant schedule improvement and a reduction in production cycle times through concurrence of traditional engineering and Manufacturing Engineering tasks.

LMTAS deployed six process quality policies that resulted in a 96% improvement in the engineering change rate on the F-16 aircraft from Block 50 to Block 50D. The policies required that all engineering design (hardware and software) were to be correct and complete before release; all manufacturing planning/work instructions/procedures were to be correct to engineering design/requirements, adequate to perform the task, and followed in the manufacturing process; all production tooling had to be able to yield conforming parts; all nonconforming parts were to be identified and rejected at the earliest point of manufacturing; in addition, no open Quality Action Request products were to be moved to the next step of manufacturing; all repetitive occurrences of non-conformances had to be identified and corrected; and all nonconforming supplier parts were to be rejected and returned to the manufacturer.

LMTAS made these changes quickly and used these policies to instill process ownership, implement SPC, monitor work instructions, establish preventive maintenance programs, train employees, and identify root causes of nonconforming parts.

## DESIGN ANALYSIS

### Design Cost Integration

LMTAS is instituting a new system to perform design cost analysis and improve on its existing capability. The objective of the effort is to develop a tool set that will provide an integrated approach to bringing all aspects of costing such as engineering, material, and manufacturing together through a central interface. The system could be used to provide an audit trail for identification of cost drivers, perform cost trades throughout the design/development cycle with continually improving quality and turnaround, and provide design/manufacturing guidance based on accurate cost projections.

A benchmarking study, completed in 1994, investigated existing systems and determined that the Cost Advantage System by Cognition offered the best available solution. The Cost Advantage system is a knowledge-based expert system shell offering flexibility in model construction from very high level data to extreme detail. The system architecture is structured around the knowledge base in two sections – a builder section and a user section (Figure 3-1). The builder section is constructed around a user-friendly, natural-language interface with easy-to-follow forms that guide

the user through the model construction process. The system includes an inference engine that can associate tolerances with functions that allow constructing knowledge bases based on operations.

The system is being developed around Cost Assessment Program for Structures, and Producibility and Cost Analysis System. The approach is to use the Cognition Cost Advantage software to capture various manufacturing process knowledge and associated cost for various part families and their features.

## PROTOTYPE DEVELOPMENT AND REVIEW

### Product Modeling and Simulation

LMTAS extensively uses product modeling and simulation to improve product development and communication, and to more effectively serve the customers' needs. Besides the obvious benefits gained during the design process, LMTAS is using design definition data to create simulations for training and marketing needs. Current analysis applications of modeling include fatigue/fracture, post failure, temperature and stress analysis. Simulations performed include inspection, NC machining, forming, bird strikes, and many other simulations.

Because the ability to influence product cost drops exponentially during product development, it is increasingly important to provide as much design information as early as possible. This can be accomplished when the conceptual design models are modeled electronically and this information can be flowed down through all phases of the product development cycle. This allows for concurrent product development, virtually eliminating the need for mock-ups, and

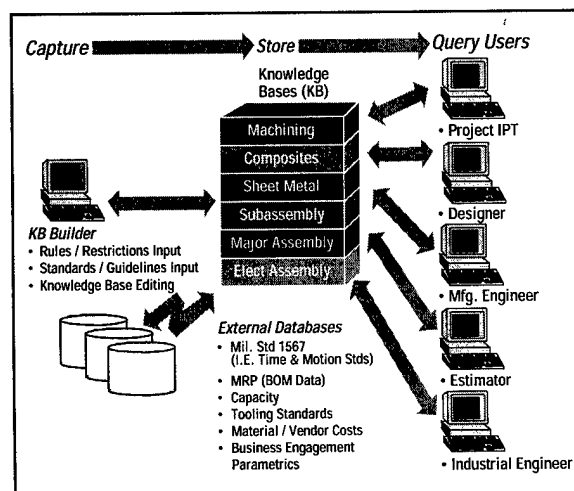


FIGURE 3-1. COST ADVANTAGE ARCHITECTURE

---

increases the quality of the information at the interface of each product development function. Although manufacturing and design approach the information with different functional needs, the core product definition data should be identical.

One example of efficiency has been realized by using COMOK for mock-ups and by electronic simulation of live fire tests. This is the use of hydrodynamic ram simulations to understand the response of live-fire testing of a wing fuel tank structure. The physical test cost to fabricate, instrument, and test was about 10% of the corresponding computer simulation cost. In the same sense that computational fluid dynamics is a tool used to augment wind tunnel testing, the hydrodynamic ram simulation allowed fewer physical tests. As new programs are planned and initiated, LMTAS continues to integrate modeling and simulation as a standard practice.

### **3.3 PRODUCTION**

#### **DEFECT CONTROL**

##### **Variability Reduction**

The objective of the VR process at LMTAS is to improve the quality of products and services by minimizing variations in their manufacturing processes. This VR process is becoming institutionalized within the company, and it provides a set of tools and procedures that can be used to successfully achieve VR. A team has been formed to help define requirements, provide awareness training, and support implementation on specific programs and throughout the supplier base. The team is led by research and engineering.

At the company level, a standard practice requires VR be applied to all new programs. At the department level instructions are provided on how to satisfy VR requirements. Awareness efforts include the use of posters, videotapes, surveys, newsletters, and seminars. Support provided by the VR team includes development and publishing of a VR Guidebook, conducting formal training classes, distributing VR tool brochures, and providing consultants to facilitators. Implementation efforts have included widespread use throughout design phases, a VR requirement in the F-22 program contract, a supplier SPC certification program and widespread use of SPC throughout manufacturing on the F-16 program.

### **3.4 FACILITIES**

#### **MODERNIZATION**

##### **Process Development Center**

LMTAS has recently opened a composites Process Development Center (PDC) which will give it an innovative,

integrated, interdisciplinary development center for achieving excellence in composites products and processes. The purpose of this center is pre-production development and proofing of designs, processes, tools, methods, and procedures for low-cost, high-quality, structurally-efficient composite structures. With the addition of this center, both engineering and shop personnel have the opportunity to accomplish hands-on development of new processes and products.

The center is supported by on-site design engineers, manufacturing engineers, and shop support personnel who are tasked to complete specific tasks along with general research tasks. As a process is refined, it is then taken to the manufacturing floor where personnel from the PDC train shop personnel in integrating the new process into daily production tasks.

Another project underway at the PDC is the direct linkage of design data with key manufacturing equipment. This key manufacturing equipment includes laser ply projectors ply flattening software and CATIA downlink protocols for an ultrasonic cutter that was developed and manufactured by American GFM Corporation, Chesapeake, Virginia. Sensor feedback control of thermal processes through artificial intelligence software and embedded sensors in the composite structures is also under development.

This PDC at LMTAS should help the company to remain at the leading edge of composite technology and achieve excellence in developing new composite products and processes.

### **3.5 LOGISTICS**

#### **TRAINING MATERIALS**

##### **Research and Engineering Learning Resource Center**

LMTAS recognizes the need for increased productivity and efficiency, and one critical way to achieve this need is to develop and maintain a well-trained and motivated workforce. Time and budget constraints have demanded an alternative to traditional classroom training. LMTAS believes that it is the responsibility of the employee to strive for professional and personal development. In an attempt to address the issue of decreasing training dollars and to assist its employees in personal development, the company has devised an innovative solution that satisfies both needs.

The Research and Engineering division of LMTAS has developed a learning resource center which does not focus exclusively on instructor-led training. This center contains 10 PCs, six of which have interactive disk capability and CD ROM capability. An extensive library of the latest and most needed training aids (course materials, videodisk, and

videotape) is maintained and is available for use by all employees. One advantage of this teaching media is that the courseware is recyclable and upgradeable. Another advantage for both the employee and LMTAS is that the videotape series can be checked out by the employee and used at home as required.

There are many financial benefits derived by LMTAS from this type of learning center. Training is completed in 60% less time than traditional instructor-led training. The training cost is lowered by as much as 39%. Seventy-one percent of the 1995 training was completed on employees' personal time either at home or during working hours, leaving LMTAS with an average savings of \$16K per month.

The employees have also benefited from this type of training opportunity in that they have access to a wider variety of subjects, can retain more information (long- and short-term), and the training is more just-in-time than instructor-led.

With the establishment of this learning resource center, LMTAS maintains that it has built a strong, well-trained work force, delivered alternative training on major topics, reduced long-term training cost and consequently passed these savings on to its customers. Future plans for the center include continued upgrades and just-in-time, on-line delivery of courseware, scheduling information, and training histories directly to the employees' desktop.

### **3.6 MANAGEMENT**

## **MANUFACTURING STRATEGY**

### **Flight Control Systems Teaming**

Teaming has been evaluated by Lockheed Martin Tactical Aircraft Systems (LMTAS) because of the complex flight control systems development processes occurring in 1980 on the AFTI/F-16.

The goal of the AFTI/F-16 flight control design was to make state-of-the-art advancements. The design was not progressing satisfactorily; therefore, major changes in development philosophy were required to solve the problems and meet the challenges of the new program. The major difficulty was communication. Problem areas were rooted in poor communications within and between the various flight control technical disciplines. A mechanization team was formed with lead engineers from all the technical disciplines involved in the integrated systems design. The team compelled all "changes" to be well documented, forcing all accountability to the team for the technical accuracy and efficiency. Teams work best when they can focus their energy on the primary objectives and not processes or personnel problems.

Two primary organizational structure variations have been explored over the last 15 years – a team as an organizational unit, and the team supported by a matrix organization. The LMTAS flight control systems organization determined that in this complex systems area, a team supported by the matrix organization works best. Since the 1980 inception of the first flight controls integration team effort:

1. The organizational structure that supports a team can be a major contributor to its success.
2. Effective teaming is a mind set.
  - Each team member accepts the idea that the team can do a better job as a group than as individuals.
  - Each team member willingly shares his or her expertise.
  - Team members trust other members to watch after the team interests.
  - Team members work toward a consensus; they are willing to support the consensus even if they are not strong supporters of the decision.
3. Environmental factors can be overestimated.
  - Collocation and special communication databases can significantly aid but are not necessary to establish an effective team.
  - Not all teams can afford or require full-time members in all disciplines.
4. Documentation must be integral to the team processes.
5. Be patient.
6. Keep detailed process flow charts in perspective.
7. If it must change rapidly or frequently – develop it in house.
8. Get the end user (pilot) involved in the process as early as possible.

Teaming comes in many styles and there is no single best way to team. According to LMTAS, good teams seem to have the following attributes: achievement of a team mind set, true empowerment to accomplish the team objectives, a support organization that lets the team focus on its objectives, and the flexibility to adapt to change.

### **Commercialization**

To address the growing need for acquisition reform and streamline the acquisition process, LMTAS has proposed to apply commercial business practices to its existing F-16 production program under a pilot plant program. This commercialization approach goes well beyond the current acquisition reform efforts and will require DoD sponsorship and legislative guidance. This proposal will provide

**TABLE 3-1. COMMERCIAL OPERATING CONCEPTS**

- Company Processes Replace Mil Standards
- TINA and Proposal Support Eliminated
- No C/SCSC Reporting
- Simplified MRP
- Configuration Management Simplified
- ISO-9001 Certification/Registration Replaces MIL-Q-9858
- Commercial Contracts
- Performance-Based System Specification
- Payment Schedule Replaces Progress Payments
- Simplified Cost Accounting System
- Minimum Data Deliverables

potentially significant savings and aggressively address the increasing interest in commercialization.

The existing F-16 baseline will allow for valuable benchmarking of acquisition reform and provide a measurement of true savings using commercial practices. Some processes in this pilot program include process controls, and continuous improvement, and the elimination of DOD oversight. The plan also includes transitioning all Government Furnished Equipment to Contractor Furnished Equipment for all commercial operations, and the establishment of commercial partnerships with suppliers. Commercial

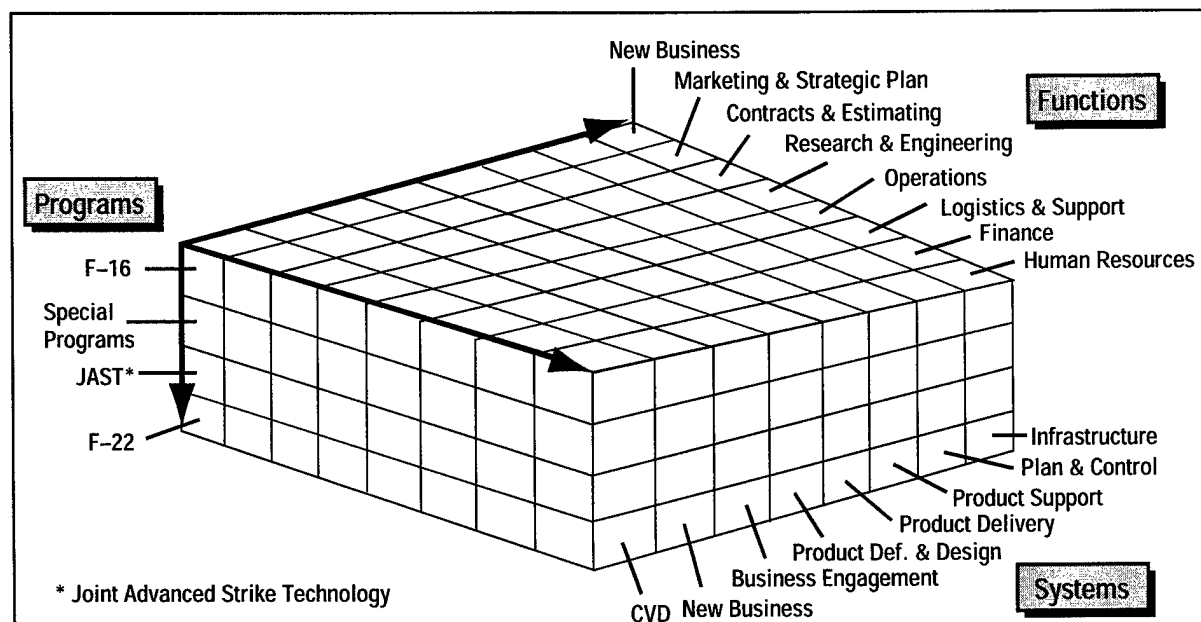
practices and operating concepts are proposed to replace DOD-specific requirements (Table 3-1). Essentially, LMTAS proposes that the government control the performance requirements, while it controls the details of implementation. With this pilot program, LMTAS is essentially guaranteeing a reduced price for a proven product, the F-16, and also for new aircraft procurements.

LMTAS' pilot plant approach has the potential to be a pathfinder for broad acquisition reform. It is a unique approach to implement commercial practices into defense procurement, and provide a viable alternative to enhance the defense industry.

### Product Definition and Design Business System

LMTAS is evolving its organizational structure to support a product definition and design business system supplying proven build-to packages to a product delivery system. This effort will streamline the procurement, fabrication, assembly, and delivery of tactical aircraft and related systems. Concepts under consideration address structuring the organization around product design teams that would continue the focus on development of build-to packages that encompass tool designs, work instructions, and Bills of Material.

The current organization features business area managers who are responsible for core business units. These business units are matrixed with traditional functional units to support individual programs (Figure 3-2). A horizontal slice



**FIGURE 3-2. PROGRAMS, FUNCTIONS, AND BUSINESS RELATIONSHIPS**

---

through this three-dimensional matrix structure would produce an integrated product team for a specific program. A study examining the interfaces in the current core business systems approach determined that a key interface point existed in translating product descriptions into product support and product delivery operations. The study also highlighted the value of integrating manufacturing engineering into the engineering organization. This integration began in August 1994 and is projected to be completed by January 1996.

One conceptual model under consideration would establish product departments that could draw from a process-technology-tools organization and be supported by a services and laboratory organization. The laboratory organization provides infrastructure support. For example, a typical product department might be airframes or avionics. These departments could be broken down into sections supporting specific programs. The sections would be further divided into product teams.

Other organizational concepts being considered would have a product-oriented structure focusing on build-to package responsibilities. These concepts have been studied by comparing existing program schedules against revised schedules based on the proposed approach. These studies have shown schedule improvements of as much as eight months on some critical path components.

## Quick Reaction Procurement

In 1991, LMTAS decided it needed to streamline its procurement process for orders under \$2.5K to reduce the costly related administrative costs. While developing a system, LMTAS researched the Federal Acquisition Regulations Part 13.106 for guidance and discovered that the FAR does not prohibit the awards of contracts up to \$2.5K without competitive bids if the price is determined to be reasonable. LMTAS then reviewed its existing material department procedures for purchase order placement, documentation, archiving/storage, and associated costs and determined that there was no specific procedure that existed for small purchases.

From this review came the development of the Quick Reaction Procurement process. A new procedure was developed specifically to address purchase orders of less than \$2.5K. The criteria for source selection and price justification were based on buyer judgement, price/award history, and market conditions. The system incorporated on-line documentation, signature authority, eliminated storage space, reduced hard copy requirements, and blanket purchase agreements were established to streamline the process.

The Quick Reaction Procurement is limited to non-production items and covers materials that are typically needed as soon as possible and where minimal inspection is

required. Through the Quick Reaction Procurement system, LMTAS can reduce administrative costs significantly, reduce order time, and ultimately provide a better product to the customer.

## Electronic Procurement Process

LMTAS has been developing an Electronic Procurement Process since 1994 with numerous objectives, among the most important to decrease cycle time and create a central procurement processing capability. The key to the LMTAS approach is to connect the procurement process with the supplier electronically. Long-term agreements defining part numbers, price, terms, and lead time are established with suppliers. The procurement process is thereby greatly reduced and allows for more efficient manufacturing operations. Once an agreement has been reached, orders are automatically placed for part numbers defined in the terms. If agreements are not developed, the system routes the purchase request to a buyer for exception processing.

The Electronic Procurement Processing system allows LMTAS to partner with the supplier and become a team in satisfying production needs. The overall impact to LMTAS customers is reduced schedule and prices. The Electronic Procurement Process system is presently in confidence testing and will be fully on-line in the fall of 1995.

## Information Resource Management

The role of the Information Resource Management (IRM) organization at LMTAS is to provide information technology to support the requirements of the core business systems. Much is accomplished through outsourcing in a unique relationship with Computer Sciences Corporation (CSC). The IRM organization is an operation that provides leadership, expertise, and oversight. Requirements and planning are coordinated through an Information Resource Council comprised of the major functional and business area units and chaired by IRM. Certain critical functions have been retained by the LMTAS functional organizations and IRM organization. These include product software and embedded software development, simulators, and voice telecommunications.

Most other information resource functions, however, are supported by CSC in a unique and symbiotic arrangement. Under the terms of a ten-year agreement, CSC provides almost all computing services for LMTAS. This outsourcing arrangement is controlled through an annual services agreement. Much of the equipment and many personnel supporting this arrangement were acquired by CSC from LMTAS. Most of the annual services are contracted on a cost-plus-fixed-fee basis. CSC receives incentive fees for approved cost reduction proposals and for reducing overhead. Under certain circumstances, prices can be renegotiated during the year.

Types of services handled by CSC include computer processing, business information systems, CAD/CAM/CAE, engineering and other technical systems, networking and data communications, telecommunications services excluding voice communications, electronic security, and computer related training. This arrangement has allowed LMTAS to reduce information system costs greatly while maintaining high quality and service and retaining critical functions in-house.

## PERSONNEL REQUIREMENTS

### Employee Involvement

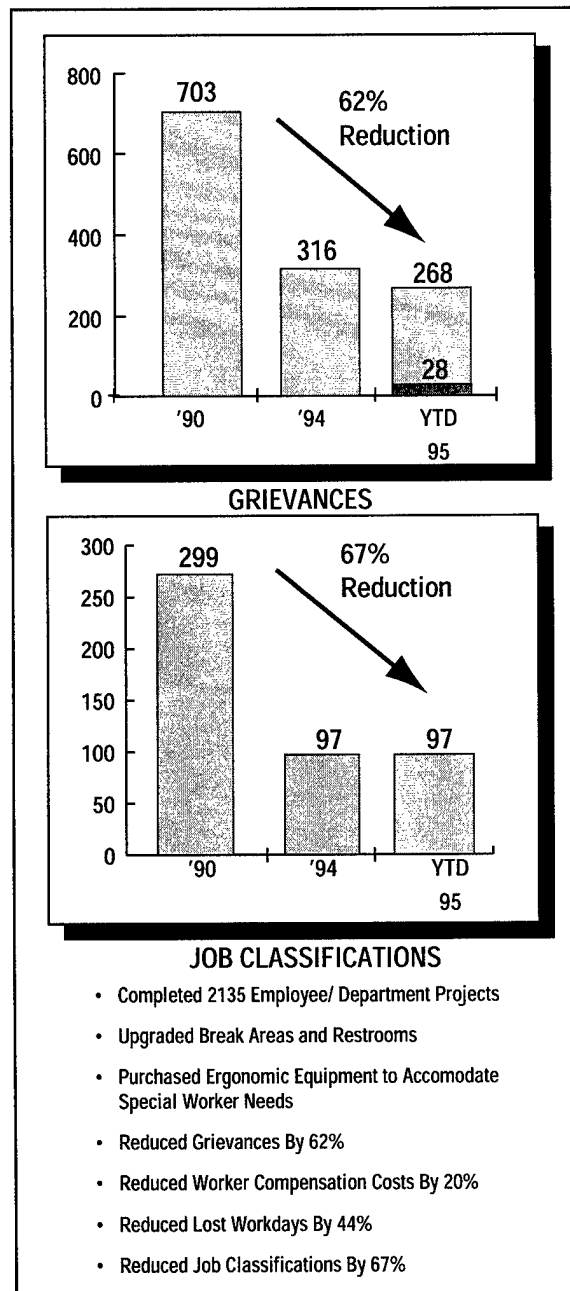
LMTAS is working to maintain productivity and improve the quality of its work environment as it accepts the challenge to create a lean manufacturing environment. While it improved schedules and cost, LMTAS management realized that it must listen to the needs of the factory workers and encourage communication among all tiers of personnel (Figure 3-3).

The company is improving personnel relationships by completing 2135 employee/department projects. For example, it has upgraded break areas and rest rooms, and machine operators have been asked to provide input toward modification of tooling to accommodate their special needs. The company has purchased ergonomic equipment to ease factory floor discomfort (Table 3-2).

Increased communications and concern for the employees have reduced grievances by 62%, reduced worker compensation costs by 20%, reduced lost workdays by 44%, and reduced job classifications by 67%. IPTs are working to bring concerns to management attention. Daily meetings have been held in some factory areas for the last 3-4 years to discuss safety, concerns, schedules, and tooling. LMTAS upper level management provides an open-door policy with production personnel by participating in

**TABLE 3-2. SYSTEM IMPROVEMENTS**

	WAS	NOW
• Inventory Accuracy	79%	98.6%
• Bill of Material Accuracy	72%	99.9%
• Bill of Material Backlog	17,000+ Hrs	3,000 Hrs
• WIP Accuracy	85%	99.2%
• Kit Accuracy	Not Measured	100%
• Dispatch List Adherence	79.9%	97.5%
• Router Accuracy	Not Measured	99.1%
• Behind Schedule Order Releases	83%	1.4%
• Reduced # of Operating Systems	2	1



**FIGURE 3-3. IMPROVED PEOPLE RELATIONSHIPS**

breakfast and lunch meetings to discuss issues. Management has also initiated an issue-and-concern board to address any employee questions.

During the height of the rightsizing, LMTAS provided a transition center to help employees in preparing resumes, searching for jobs, and offering training to employees pursuing a career change.

---

## DATA REQUIREMENTS

### Electronic Data Interchange

LMTAS has initiated electronic data interchange (EDI) with members of its supplier base for electronic exchange of routine business documents. This implementation of EDI was driven by top management to improve the procurement process. Cross-functional teams were formed to select suppliers to target, develop strategic planning, determine transaction sets, quantify the performance baseline, develop operating procedures and processes, and initiate training in the use of EDI.

The system works through a Value Added Network which is predominantly an electronic mail box. LMTAS transfers data such as purchase orders, funds, purchase order changes and supplements, requests for quote, and responses to request for quotes. Other data transfer is anticipated such as planning schedules, text messages, advanced ship notices, material safety data sheets, specification and technical information, and price sales catalogues.

EDI is presently used with 300 suppliers and encompasses approximately 80% of all purchase orders. LMTAS has benefited by reduced inventory, lower data entry errors, decreased mailing, storage, and archiving costs, reduced order time, decreased paper and reproduction costs, more timely and accurate decision making information, and easier functional/process changes.

## QUALITY ASSURANCE

### Process Quality Assurance

LMTAS teamed quality assurance and manufacturing personnel and developed a Process Quality Assurance Organization in a nontraditional approach to solving quality issues. This organization is comprised of planning, engineering, manufacturing, quality, and manufacturing engineering personnel. The team has the responsibilities of eliminating or minimizing causes of nonconformance and developing corrective actions that identify necessary actions, assigning implementation activities, and establishing completion dates.

The teams are also responsible for verifying the effectiveness of the corrective actions taken. Teams are collocated on the production floor to support manufacturing and to offer production personnel product expertise and quick problem resolution for a specific aspect of tactical aircraft manufacturing.

LMTAS staffs, maintains, and conducts Material Review Boards (MRBs) for disposition on nonconformance products. However, since the implementation of its Process

Quality Assurance Organization, its MRB processing time has been reduced by 266%. This almost instantaneous resolution allows manufacturing to maintain less work in process and enhance schedule compliance which also reduces cost.

### SPC Supplier Certification

The SPC Supplier Certification program is an initiative under the LMTAS Supplier Relations Program requiring that all suppliers use statistical methods and techniques to analyze their processes and outputs for reducing costs and improving product quality.

LMTAS recognized that no other tool offers the opportunity to improve efficiency in all elements of cost more than SPC, not only in its own internal manufacturing processes and product output, but in the processes and output of its suppliers. In keeping with the supplier base focus to affect cost/schedule/quality, LMTAS initiated a volunteer program in 1988 for suppliers to use SPC, but met with only limited success.

Realizing that the program needed to be enforced, LMTAS initiated an 18-month effort to establish SPC as a contractual requirement with all suppliers to be certified by June 1992. LMTAS blocked all non-certified suppliers from procurement consideration and required suppliers to become SPC certified before purchase order award. Unique to the program is that LMTAS did not dictate how SPC techniques are used, but did apply measures to assure the supplier's SPC system was effective.

LMTAS identified not only the requirements, but the beneficial gains achievable by the supplier through SPC. The program requirements are well defined and documented for both the administration of the program by LMTAS and the participation in the program by the suppliers. Workshops, conferences, and training sessions are held to clarify requirements and help the supplier base conform to the SPC Certification Requirements. The program has generated SPC approval requirements, certification requirements, continued certification requirements, and system controls. A certified supplier must have knowledge of SPC at all levels, have managements' involvement and participation at all levels, develop SPC procedures, understand process deviation, apply SPC effectively, and continually work to improve processes and products. The supplier is awarded SPC System Certification after successfully passing a self evaluation, an audit by LMTAS, schedule and performance evaluation, deficiency corrections, and certification that all requirements are met.

As of July 1995, 564 suppliers out of the supplier base of 602 have been SPC certified, with 31 additional suppliers committed to and working toward SPC certification. Benefits to the supplier have been increased business and in-

---

creased profit margins. Improved supplier performance has contributed to the overall unit price reductions of 38%, although production rates are lower than in the past. LMTAS has improved their Purchased Material Acceptance Rate from suppliers from 96% to 99.9% – highest in the history of the plant. Their Purchase Order Delivery Concurrency has improved from 89% to 98% – highest in the history of the plant.

## STAR Preferred Supplier Program

LMTAS's preferred supplier program helps decrease costs associated with ensuring acceptable quality from its suppliers, while enhancing the suppliers' confidence levels. This program, called the STAR Supplier Program, was established in mid-1994 and since that time, 47 of the total 601 production suppliers have been classified as STAR participants. Forty-one more suppliers are currently under consideration.

To qualify as a STAR participant, the supplier must meet the selection criteria for quality, schedule, and cost. The acceptable quality level criteria includes a supplier maintaining an LMTAS SPC System Certification in accordance with mandatory contract requirements. The supplier must have maintained zero percent rejections at a designated point of inspection during the 6-month period prior to consideration. Additionally, it must have maintained a zero nonconformance cost during this same period. The second criteria for selection is ratio of on-time deliveries to purchase order schedule must be 98% or higher. Untimely deliveries are not only considered to be those delivered after the scheduled time, but before as well. As the primary cost criteria, the supplier must show a decreasing price trend over the life of the program. It must demonstrate a responsiveness to cost containment initiatives and give prompt acknowledgments, reports, and compliance with requirement changes. In general, it should demonstrate a commitment to the program.

Once a supplier has been designated as meeting the candidate selection criteria, validation of the results takes place in the form of a STAR Quality System Audit. Additionally, a formal surveillance plan is developed that establishes manufacturing process flow validation points, frequency of on-site visits, and product audit checklists. The results of these activities are then presented to the Executive Steering Committee for STAR supplier approval.

Once selected as a STAR participant, the supplier must show continuation of its performance through limited post-award surveillance. Incremental and unannounced surveillance visits of the supplier are performed by designated surveillance representatives. Furthermore, formal STAR performance reviews are conducted by the Executive Steering Committee on an arbitrary basis to

consider certification validation of the supplier. Non-conformances are treated in a highly cooperative manner to promote prompt corrective action. Letters of concern are sent to senior management for items such as issuance of a minor waiver and failure of an in-process audit at the facility. Suspension may occur for items as issuance of a major waiver or repetition of in-process audit failures. The supplier is only removed if it loses its SPC System Certification, shows repetitive corrective action milestone schedule failures, or fails to maintain effective corrective actions.

The benefits obtained by the affected suppliers are a reduction in facility oversight by LMTAS and Lockheed corporate recognition. Benefits to LMTAS include confidence in top quality product buys through a strategic alliance of preferred suppliers, on-time delivery assurance, and reduction in product costs. To date, Lockheed has reduced supplier expenses by over \$320K and decreased the personnel required to oversee supplier activity. As a result of proactive relations between Lockheed and its preferred suppliers, no STAR participants have been removed from the program.

## Supplier Lead Time Reduction

LMTAS initiated a schedule review program called Supplier Lead Time Reduction to reduce the production cycle of an aircraft assembly from 42 months to 24 months. All elements of the production cycle were reviewed for improvement including authorization, planning and control, requirements analysis, solutions definition, products and processes description, design descriptions proof, acceptance establishment, procurement, fabrication, and component assembly.

The results of the review showed that the procurement element individually contributed to 30 months of the production cycle. Major aircraft components such as valves, actuators, pumps, landing gear, and government-furnished equipment had long lead times that extended beyond 24 months. The procurement managers of these major components were asked to perform a lead time reduction analysis and attempt to meet the 24-month target.

Supplier surveys were sent, asking the supplier to rate various factors that contributed to long lead times. A high rating indicated that the factor is an important driver of the lead time. Suppliers were also asked to what extent LMTAS drove the supplier's lead times. The survey included such factors as military standards requirements, impacts driven by the government, revision processes, lack of up-front supplier involvement, inspections, communications, unclear or incomplete specifications, certification process, administrative activities, paperwork, inadequate computer systems, scrap/rework, and many other factors that affect the lead time.

---

The findings of the Supplier Lead time Reduction review identified the procurement cycle, government furnished equipment, and LMTAS all contributed to the 42-month production cycle with LMTAS being responsible for the largest portion of the cycle. LMTAS addressed these areas by forming alliances with the supplier, establishing new

guidelines for purchases less than \$2.5K, using letter contracts instead of definitive contracts, group reviews versus sequential reviews, and supplier conferences.

Through this and other efforts to work with the supplier, LMTAS has reduced the lead time of most procured items to 24 months or less.

---

# APPENDIX A

## TABLE OF ACRONYMS

---

ACRONYM	DEFINITION
ABC	Activity-Based Cost
ACAD	Advanced Computer-Aided Design
ASE	Avionics Simulation Environment
BMP	Best Manufacturing Practices
CATIA	Computer-Aided Three-Dimensional Interface Applications
CIS	Core Integration Station
COMOK	Computer Mock-up
CPU	Cost Per Equivalent Unit
CSC	Computer Sciences Corporation
DoD	Department of Defense
EDI	Electronic Data Interchange
ESDR	Engineering Source Data Requirements
FSS	Fuel System Simulator
IPD	Integrated Product Development
IRM	Information Resource Management
IRP	Internal Review Process
LMTAS	Lockheed Martin Tactical Aircraft Systems
LSA	Logistic Support Analysis
MMC	Modular Mission Computer
MRB	Material Review Board
P3V	Product Proof and Prototype Validation
PD&D	Product Definition and Design
PDC	Process Development Center
QP#1	Quality Policy #1
RCA	Root Cause Analysis
RFP	Request for Proposal
SEPG	Software Engineering Process Group
SIRT	Simulation Integration Review Team
SPC	Statistical Process Control
SPEAR	Supplier Performance Evaluation and Review
SPM	Supplier Performance Metric
VR	Variability Reduction
WBS	Work Breakdown Structure

# APPENDIX B

## ***BMP SURVEY TEAM***

---

<b>TEAM MEMBER</b>	<b>ACTIVITY</b>	<b>FUNCTION</b>
<b>Larry Robertson</b> (812) 854-5336	<b>Crane Division</b> <b>Naval Surface Warfare Center</b> Crane, IN	<b>Team Chairman</b>
<b>Amy Scanlan</b> (301) 403-8100	<b>BMP Center of Excellence</b> College Park, MD	<b>Technical Writer</b>
<b>DESIGN/TEST</b>		
<b>Bob Jenkins</b> (703)602-3003	<b>Naval Sea Systems Command</b> Washington, DC	<b>Team Leader</b>
<b>Dan Geuder</b> (812) 854-6432	<b>Crane Division</b> <b>Naval Surface Warfare Center</b> Crane, IN	
<b>Jeff Bohanan</b> (615) 574-3438	<b>Oak Ridge National Laboratories</b> Oak Ridge, TN	
<b>PRODUCTION/FACILITIES</b>		
<b>Jack Tamargo</b> (707) 642-4267	<b>BMP West Coast Representative</b> Vallejo, CA	<b>Team Leader</b>
<b>Don Hill</b> (317) 306-3781	<b>Naval Air Warfare Center</b> <b>Aircraft Division - Indianapolis</b> Indianapolis, IN	
<b>Tom Kirchner</b> (317) 306-7217	<b>Naval Air Warfare Center</b> <b>Aircraft Division - Indianapolis</b> Indianapolis, IN	
<b>MANAGEMENT/LOGISTICS TEAM #1</b>		
<b>Rick Purcell</b> (301) 403-8100	<b>BMP Center of Excellence</b> College Park, MD	<b>Team Leader</b>
<b>Karon Myles</b> (909) 273-4951	<b>Naval Warfare Assessment Division</b> Corona, CA	
<b>Clint McCormick</b> (317) 306-3361	<b>Naval Air Warfare Center</b> <b>Aircraft Division - Indianapolis</b> Indianapolis, IN	

---

<b>NAME</b>	<b>ACTIVITY</b>	<b>FUNCTION</b>
	<b>MANAGEMENT/LOGISTICS TEAM #2</b>	
<b>Larry Halbig</b> (317) 306-3838	<b>Naval Air Warfare Center</b> <b>Aircraft Division - Indianapolis</b> Indianapolis, IN	<b>Team Leader</b>
<b>Nick Keller</b> (812) 854-5331	<b>Crane Division</b> <b>Naval Surface Warfare Center</b> Crane, IN	
<b>Karon Myles</b> (909) 273-4968	<b>Naval Warfare Assessment Division</b> Corona, CA	

---

# APPENDIX C

## PROGRAM MANAGER'S WORKSTATION

---

The Program Manager's Workstation (PMWS) is a series of expert systems that provides the user with knowledge, insight, and experience on how to manage a program, address technical risk management, and find solutions that industry leaders are using to reduce technical risk and improve quality and productivity. This system is divided into four main components; KNOW-HOW, Technical Risk Identification and Mitigation System (TRIMS), BMP Database, and Best Manufacturing Practices Network (BMPnet).

- **KNOW-HOW** is an intelligent, automated method that turns "Handbooks" into expert systems, or digitized text. It provides rapid access to information in existing handbooks including Acquisition Streamlining, Non-Development Items, Value Engineering, NAVSO P-6071 (Best Practices Manual), MIL-STD-2167/2168, SecNav 5000.2A and the DoD 5000 series documents.
- **TRIMS** is based on DoD 4245.7-M (the transition templates), NAVSO P-6071 and DoD 5000 event oriented acquisition. It identifies and ranks the high risk areas in a program. TRIMS conducts a full range of risk assessments throughout the acquisition process so corrective action can be initiated before risks develop into problems. It also tracks key project documentation from concept through production including goals, responsible personnel, and next action dates for future activities in the development and acquisition process.
- The **BMP Database** draws information from industry, government, and the academic communities to include documented and proven best practices in design, test, production, facilities, management, and logistics. Each

practice in the database has been observed and verified by a team of experienced government engineers. All information gathered from BMP surveys is included in the BMP Database, including this survey report.

- **BMPnet** provides communication between all PMWS users. Features include downloading of all programs, E-mail, file transfer, help "lines", Special Interest Groups (SIGs), electronic conference rooms and much

more. Through BMPnet, IBM or compatible PC's and Macintosh computers can run all PMWS programs.

- To access **BMPnet** efficiently, users need a special modem program. This program can be obtained by calling the BMPnet using a VT-100/200 terminal emulator set to 8,N,1. Dial (703) 538-7697 for 2400 baud modems and (703) 538-7267 for 9600 baud and 14.4 kb. When asked for a

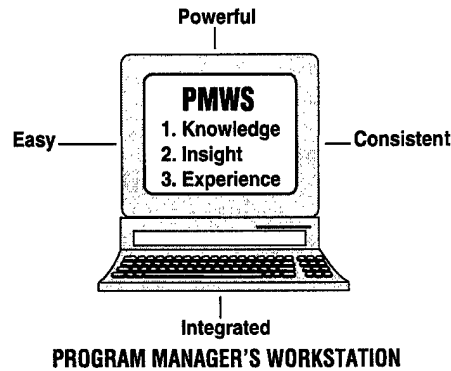
user profile, type: DOWNPC or DOWNMAC <return> as appropriate. This will automatically start the Download of our special modem program. You can then call back using this program and access all BMPnet functions. The General User account is:

USER PROFILE: BMPNET

USER I.D.: BMP

Password: BMPNET

If you desire your own personal account (so that you may receive E-Mail), just E-Mail a request to either Ernie Renner (BMP Director) or Brian Willoughby (CSC Program Manager). If you encounter problems please call (703) 538-7253.



# APPENDIX D

## NAVY CENTERS OF EXCELLENCE

---

### **Automated Manufacturing Research Facility**

(301) 975-3414

The Automated Manufacturing Research Facility (AMRF) – a National Center of Excellence – is a research test bed at the National Institute of Standards and Technology located in Gaithersburg, Maryland. The AMRF produces technical results and transfers them to the Navy and industry to solve problems of automated manufacturing. The AMRF supports the technical work required for developing industry standards for automated manufacturing. It is a common ground where industry, academia, and government work together to address pressing national needs for increased quality, greater flexibility, reduced costs, and shorter manufacturing cycle times. These needs drive the adoption of new computer-integrated manufacturing technology in both civilian and defense sectors. The AMRF is meeting the challenge of integrating these technologies into practical, working manufacturing systems.

### **Electronics Manufacturing Productivity Facility**

(317) 226-5607

Located in Indianapolis, Indiana, the Electronics Manufacturing Productivity Facility (EMPF) is a National Center of Excellence established to advance state-of-the-art electronics and to increase productivity in electronics manufacturing. The EMPF works with industry, academia, and government to identify, develop, transfer, and implement innovative electronics manufacturing technologies, processes, and practices. The EMPF conducts applied research, development, and proof-of-concept electronics manufacturing and design technologies, processes, and practices. It also seeks to improve education and training curricula, instruction, and necessary delivery methods. In addition, the EMPF is striving to identify, implement, and promote new electronics manufacturing technologies, processes, materials, and practices that will eliminate or reduce damage to the environment.

### **National Center for Excellence in Metalworking Technology**

(814) 269-2420

The National Center for Excellence in Metalworking Technology (NCEMT) is located in Johnstown, Pennsylvania and is operated by Concurrent Technologies Corporation (CTC), a subsidiary of the University of Pittsburgh Trust. In support of the NCEMT mission, CTC's primary focus includes working with government and industry to develop improved manufacturing technologies including advanced methods, materials, and processes, and transfer-

ring those technologies into industrial applications. CTC maintains capabilities in discrete part design, computerized process analysis and modeling, environmentally compliant manufacturing processes, and the application of advanced information science technologies to product and process integration.

### **Center of Excellence for Composites Manufacturing Technology**

(414) 947-8900

The Center of Excellence for Composites Manufacturing Technology (CECMT), a national resource, is located in Kenosha, Wisconsin. Established as a cooperative effort between government and industry to develop and disseminate this technology, CECMT ensures that robust processes and products using new composites are available to manufacturers. CECMT is operated by the Great Lakes Composites Consortium. It represents a collaborative approach to provide effective advanced composites technology that can be introduced into industrial processes in a timely manner. Fostering manufacturing capabilities for composites manufacturing will enable the U.S. to achieve worldwide prominence in this critical technology.

### **Navy Joining Center**

(614) 486-9423

The Navy Joining Center (NJC) is a Center of Excellence established to provide a national resource for the development of materials joining expertise, deployment of emerging manufacturing technologies, and dissemination of information to Navy contractors, subcontractors, Navy activities, and U.S. industry.

The NJC is located in Columbus, Ohio, and is operated by Edison Welding Institute (EWI), the nation's largest industrial consortium dedicated to materials joining. The NJC combines these resources with an assortment of facilities and demonstrated capabilities from a team of industrial and academic partners. NJC technical activities are divided into three categories - Technology Development, Technology Deployment, and Technology Transfer. Technology Development maintains a goal to complete development quickly to initiate deployment activities in a timely manner. Technology Deployment includes projects for rapid deployment teaming and commercialization of specific technologies. The Technology Transfer department works to disseminate pertinent information on past and current joining technologies both at and above the shop floor.

# APPENDIX E

## ***NEW BEST MANUFACTURING PRACTICES PROGRAM TEMPLATES***

---

Since 1985, the BMP Program has applied the templates philosophy with well-documented benefits. Aside from the value of the templates, the templates methodology has proven successful in presenting and organizing technical information. Therefore, the BMP program is continuing this existing "knowledge" base by developing 17 new templates that complement the existing DoD 4245.7-M or Transition from Design to Production templates.

The development of these new templates was based in part on Defense Science Board studies that have identified new technologies and processes that have proven successful in the last few years. Increased benefits could be realized if these activities were made subsets of the existing, compatible templates.

Also, the BMP Survey teams have become experienced in classifying Best Practices and in technology transfer.

The Survey team members, experts in each of their individual fields, determined that data collected, while related to one or more template areas, was not entirely applicable. Therefore, if additional categories were available for Best Practices "mapping," technology transfer would be enhanced.

Finally, users of the Technical Risk Identification and Mitigation System (TRIMS) found that the program performed extremely well in tracking most key program documentation. However, additional categories – or templates – would allow the system to track all key documentation.

Based on the above identified areas, a core group of activities was identified and added to the "templates baseline." In addition, TRIMS was modified to allow individual users to add an unlimited number of user-specific categories, templates, and knowledge-based questions.

---

# APPENDIX F

## **COMPLETED SURVEYS**

---

BMP surveys have been conducted at the companies listed below. Copies of older survey reports may be obtained through DTIC or by accessing the BMPNET. Requests for copies of recent survey reports or inquiries regarding the BMPNET may be directed to:

Best Manufacturing Practices Program  
4321 Hartwick Rd., Suite 308  
College Park, MD 20740  
Attn: Mr. Ernie Renner, Director  
Telephone: 1-800-789-4267  
FAX: (301) 403-8180  
ernie@bmpcoe.org

### **COMPANIES SURVEYED**

Litton  
Guidance & Control Systems Division  
Woodland Hills, CA  
October 1985 and February 1991

Texas Instruments  
Defense Systems & Electronics Group  
Lewisville, TX  
May 1986 and November 1991

Harris Corporation  
Government Support Systems Division  
Syosset, NY  
September 1986

Control Data Corporation  
Government Systems Division  
(Computing Devices International)  
Minneapolis, MN  
December 1986 and October 1992

ITT  
Avionics Division  
Clifton, NJ  
September 1987

UNISYS  
Computer Systems Division  
(Paramax)  
St. Paul, MN  
November 1987

Honeywell, Incorporated  
Undersea Systems Division  
(Alliant Tech Systems, Inc.)  
Hopkins, MN  
January 1986

General Dynamics  
Pomona Division  
Pomona, CA  
August 1986

IBM Corporation  
Federal Systems Division  
Owego, NY  
October 1986

Hughes Aircraft Company  
Radar Systems Group  
Los Angeles, CA  
January 1987

Rockwell International Corporation  
Collins Defense Communications  
(Rockwell Defense Electronics  
Collins Avionics and  
Communications Division)  
October 1987 and March 1995

Motorola  
Government Electronics Group  
Scottsdale, AZ  
March 1988

---

General Dynamics  
Fort Worth Division  
Fort Worth, TX  
May 1988

Hughes Aircraft Company  
Missile Systems Group  
Tucson, AZ  
August 1988

Litton  
Data Systems Division  
Van Nuys, CA  
October 1988

McDonnell-Douglas Corporation  
McDonnell Aircraft Company  
St. Louis, MO  
January 1989

Litton  
Applied Technology Division  
San Jose, CA  
April 1989

Standard Industries  
LaMirada, CA  
June 1989

Teledyne Industries Incorporated  
Electronics Division  
Newbury Park, CA  
July 1989

Lockheed Corporation  
Missile Systems Division  
Sunnyvale, CA  
August 1989

General Electric  
Naval & Drive Turbine Systems  
Fitchburg, MA  
October 1989

TRICOR Systems, Incorporated  
Elgin, IL  
November 1989

TRW  
Military Electronics and Avionics Division  
San Diego, CA  
March 1990

Texas Instruments  
Defense Systems & Electronics Group  
Dallas, TX  
June 1988

Bell Helicopter  
Textron, Inc.  
Fort Worth, TX  
October 1988

GTE  
C<sup>3</sup> Systems Sector  
Needham Heights, MA  
November 1988

Northrop Corporation  
Aircraft Division  
Hawthorne, CA  
March 1989

Litton  
Amecom Division  
College Park, MD  
June 1989

Engineered Circuit Research, Incorporated  
Milpitas, CA  
July 1989

Lockheed Aeronautical Systems Company  
Marietta, GA  
August 1989

Westinghouse  
Electronic Systems Group  
Baltimore, MD  
September 1989

Rockwell International Corporation  
Autonetics Electronics Systems  
Anaheim, CA  
November 1989

Hughes Aircraft Company  
Ground Systems Group  
Fullerton, CA  
January 1990

MechTronics of Arizona, Inc.  
Phoenix, AZ  
April 1990

---

Boeing Aerospace & Electronics  
Corinth, TX  
May 1990

Textron Lycoming  
Stratford, CT  
November 1990

Naval Avionics Center  
Indianapolis, IN  
June 1991

Kurt Manufacturing Co.  
Minneapolis, MN  
July 1991

Raytheon Missile Systems Division  
Andover, MA  
August 1991

Tandem Computers  
Cupertino, CA  
January 1992

Conax Florida Corporation  
St. Petersburg, FL  
May 1992

Hewlett-Packard  
Palo Alto Fabrication Center  
Palo Alto, CA  
June 1992

Digital Equipment Company  
Enclosures Business  
Westfield, MA and  
Maynard, MA  
August 1992

NASA Marshall Space Flight Center  
Huntsville, AL  
January 1993

Department of Energy-  
Oak Ridge Facilities  
Operated by Martin Marietta Energy Systems, Inc.  
Oak Ridge, TN  
March 1993

Technology Matrix Consortium  
Traverse City, MI  
August 1990

Norden Systems, Inc.  
Norwalk, CT  
May 1991

United Electric Controls  
Watertown, MA  
June 1991

MagneTek Defense Systems  
Anaheim, CA  
August 1991

AT&T Federal Systems Advanced  
Technologies and AT&T Bell Laboratories  
Greensboro, NC and Whippany, NJ  
September 1991

Charleston Naval Shipyard  
Charleston, SC  
April 1992

Texas Instruments  
Semiconductor Group  
Military Products  
Midland, TX  
June 1992

Watervliet U.S. Army Arsenal  
Watervliet, NY  
July 1992

Naval Aviation Depot  
Naval Air Station  
Pensacola, FL  
November 1992

Naval Aviation Depot  
Naval Air Station  
Jacksonville, FL  
March 1993

McDonnell Douglas Aerospace  
Huntington Beach, CA  
April 1993

---

Crane Division  
Naval Surface Warfare Center  
Crane, IN and Louisville, KY  
May 1993

Philadelphia Naval Shipyard  
Philadelphia, PA  
June 1993

R. J. Reynolds Tobacco Company  
Winston-Salem, NC  
July 1993

Crystal Gateway Marriott Hotel  
Arlington, VA  
August 1993

Hamilton Standard  
Electronic Manufacturing Facility  
Farmington, CT  
October 1993

Alpha Industries, Inc  
Methuen, MA  
November 1993

Harris Semiconductor  
Melbourne, FL  
January 1994

United Defense, L.P.  
Ground Systems Division  
San Jose, CA  
March 1994

Naval Undersea Warfare Center  
Division Keyport  
Keyport, WA  
May 1994

Mason & Hanger  
Silas Mason Co., Inc.  
Middletown, IA  
July 1994

Kaiser Electronics  
San Jose, CA  
July 1994

U.S. Army  
Combat Systems Test Activity  
Aberdeen, MD  
August 1994

Stafford County Public Schools  
Stafford County, VA  
July 1994

Sandia National Laboratories  
Albuquerque, NM  
January 1995

Lockheed Martin  
Electronics & Missiles  
Orlando, FL  
April 1995

McDonnell Douglas  
Aerospace (St. Louis)  
St. Louis, MO  
May 1995

Dayton Parts, Inc.  
Dayton, OH  
June 1995

Wainwright Industries  
St. Peters, MO  
June 1995

Lockheed Martin  
Tactical Aircraft Systems  
Fort Worth, TX  
August 1995

---