REPORT OF SURVEY CONDUCTED AT

MCDONNELL AIRCRAFT COMPANY

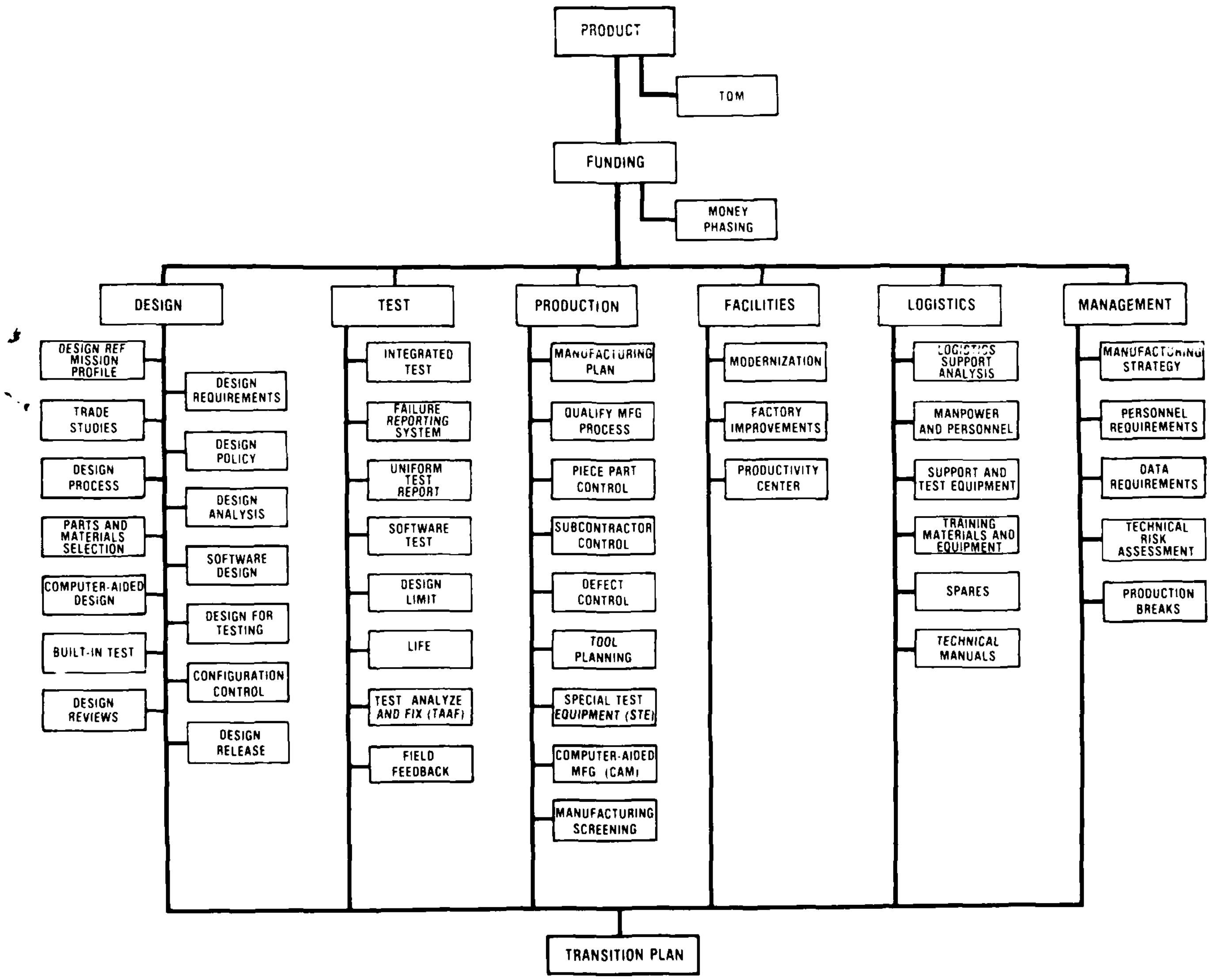
ST. LOUIS, MISSOURI

JANUARY 1989

DoD 4245.7-M

"TRANSITION FROM DEVELOPMENT TO PRODUCTION"

CRITICAL PATH TEMPLATES



CONTENTS

CONTENTS (Continued)

CONTENTS (Continued)

CONTENTS (Continued)

CONTENTS (Continued)

FIGURES

SECTION 1

EXECUTIVE SUMMARY

The Best Manufacturing Practices (BMP) team conducted a survey at McDonnell Aircraft Company (MCAIR), a component of McDonnell Douglas Corporation (MDC). The purpose of the survey was to review and document the best practices and potential industry-wide problems at MCAIR. The intent of the BMP program is to use this documentation as the initial step in a voluntary technology sharing process among the industry. The team surveyed the MCAIR facilities located in St. Louis, Missouri.

1.1 KEY FINDINGS

There were many best practices observed at MCAIR that are detailed in this report. Some of the more significant findings included in this report are summarized below:

SECTION 2

INTRODUCTION

2.1 SCOPE

The purpose of the Best Manufacturing Practices (BMP) survey conducted at McDonnell Aircraft Company (MCAIR) is to identify best practices, review manufacturing problems, and document the results. The intent is to extend the use of progressive management techniques as well as high technology equipment and processes throughout industry. The ultimate goal of the BMP program is to reduce the life cycle cost of defense systems and strengthen the U.S. industrial base by using these techniques and technologies to solve manufacturing problems and improve quality and reliability.

To accomplish this goal, a team of Navy engineers supported by representatives of the Army, Air Force, Department of Commerce, and Department of Energy accepted an invitation from MCAIR to review and document the most advanced manufacturing processes and techniques used in their facilities located in St. Louis, Missouri. The survey was conducted on January 24-27, 1989 by the team identified in Appendix B of this report.

The results of BMP surveys are entered into a database to track the best practices available in industry as well as common manufacturing problems identified by industry. The information gathered is available for dissemination through an easily accessible computer database. The actual exchange of detailed technical data will take place between contractors at their discretion on a strictly voluntary basis.

The results of this survey should not be used to rate MCAIR among other defense contractors. A contractor's willingness to participate in the BMP program and the results of a survey have no bearing on one contractor's performance over another's. The documentation in this report and other BMP reports is not intended to be all inclusive of a contractor's best practices or problems. Only selected non-proprietary practices are reviewed and documented by the BMP survey team.

2.2 SURVEY PROCESS

This survey was performed under the general survey guidelines established by the Department of the Navy. The survey concentrated on the functional areas of design, test, production, facilities, logistics, and management. The team evaluated MCAIR'S policies, practices, and strategies in these areas. Furthermore, individual practices reviewed were categorized as they relate to the critical path templates of DOD 4245.7-M, "Transition From Development To Production." MCAIR identified potential best practices and potential industry-wide problems. These practices and problems and other areas of interest identified were discussed, reviewed, and documented for dissemination throughout the U.S. industrial base.

The format for this survey consisted of formal briefings and discussions on best practices and problems. Time was spent on the factory floor reviewing practices, processes, and equipment. In-depth discussions were conducted to better understand and document the practices and problems identified.

2.3 NAVY CENTERS OF EXCELLENCE

Demonstrated industry wide problems identified during the Best Manufacturing Practices surveys may be referred to one of the Navy's Centers of Excellence. They are:

Electronics Manufacturing Productivity Facility (EMPF), Ridgecrest, CA

Applied research in the processes and materials involved in the manufacture of circuit card assemblies

Metalworking Technology, Incorporated (MTI), Johnstown, PA

Applied research in the metalworking processes

Automated Manufacturing Research Facility (AMRF), Gaithersburg, MD

Applied research in the machining processes, within a heterogenous Computer Integrated Manufacturing environment

2.4 MCDONNELL AIRCRAFT COMPANY OVERVIEW

MCAIR and MDC components occupy 1,000 acres of land in St. Louis, Missouri, most of which is adjacent to Lambert - St. Louis International Airport. Facilities include more than 200 buildings covering almost fourteen million square feet. MCAIR currently has 30,000 employees and is investing more than $1 billion in technology over a ten year period. Some of this investment is a direct result of initiatives sponsored by the Air Force Aeronautical Systems Division and the Naval Air Systems Command.

Nearly 10,000 strike fighter aircraft have rolled off MCAIR's production line since the company was founded in 1939. Current programs include the Air Force F-15E dual role fighter, the Navy and Marine Corps F/A-18 Hornet strike fighter, the Marine Corps AV-8B Harrier II, and, with General Dynamics in Fort Worth, the Navy A-12 advanced tactical aircraft. MCAIR is also teamed with Northrop in competition for the Air Force's advanced tactical fighter and teamed with McDonnell Douglas Helicopter and Bell Helicopter Textron in competition for the Army's Light Helicopter Experimental Program.

2.5 ACKNOWLEDGEMENTS

The BMP team wishes to acknowledge the efforts of Mr. Hyman Eisenberg and his staff in making this survey possible. In particular, special thanks are due to Messrs. Charles Scherrer, Gregory Stokes, and Michael Allen. Their enthusiasm for the BMP process and their support, both prior to and during the survey, contributed significantly to the success of this survey.

2.6 MCDONNELL AIRCRAFT COMPANY POINT OF CONTACT

While the information included in this report is intended to be descriptive of the best processes and techniques observed at MCAIR, it is not intended to be all inclusive. It is anticipated that the reader will need more detailed data for true technology transfer.

The reader is encouraged to contact MCAIR directly for the purpose of sharing or transferring technology. Any exchange of technology resulting from such a contact is strictly voluntary and at the discretion of MCAIR.

The MCAIR point of contact for the Best Manufacturing Practices Program is:

Mr. Hyman Eisenberg
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Research and Development
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Telephone: (314) 234-4661

SECTION 3

BEST PRACTICES

The practices listed in this section are those identified by the team as being among the best in the industry or as being particularly effective in MCAIR'S efforts to reduce the life cycle costs of its products.

3.1 DESIGN

TRADE STUDIES

MCAIR utilizes trade studies or design trade-off analyses throughout the design process to quantifiably identify the most cost effective and mission effective design approach. The trade studies for component or subassembly design consider and compare all acquisition costs.

The study on a structural component design proceeds through a series of steps in which the structural strength and sizing requirements are weighed against the component's weight and material alternatives. Design alternatives are proposed and analyzed considering the manufacturing and fabrication costs. This analysis considers the fabrication methods and procedures in detail. Tooling costs and labor hours for fabrication, engineering, and quality are estimated for the alternate component designs. A database which contains actual fabrication costs for similar components manufactured in the past is utilized.

The trade study results provide the most cost effective component design configuration. Contained in the trade study output are recurring costs for alternative configurations. These costs are associated with labor, material, expendable tooling, and quality. Non-recurring engineering cost and fixed tooling cost are also considered. The trade study develops a break-even analysis for the implementation of an alternative design. Risk assessment and schedule impact are also made available to the design team by the trade study.

SPRAYABLE INTEGRAL FUEL TANK SEALING

MCAIR has developed an alternative fuel tank sealing concept to replace conventional systems such as fillet sealing, faying surface sealing, groove sealing, adhesive sealing, and removable bladders.

This new concept involves the pneumatic application of seven layers of a material such as Loral polyurethane to interior wetted surfaces. Each layer is alternately pigmented black and white in order to establish adequate coverage during application. Eddy current techniques are employed to verify final sealant thickness.

The polyurethane sealant has undergone extensive qualification testing including mechanical properties (tensile strength and elongation at temperatures from -65^{o}F to +250^{o}F) and environmental properties (hydrolytic stability and fuel resistance). Dynamic testing has also been conducted utilizing a deflection beam fixture capable of producing 12,000 hours of the F/A-18 fatigue spectrum, a wing torque box reproducing the fatigue spectrum of the General Dynamics F-16, and a fuselage tank reproducing the F/A-18 fatigue spectrum.

Leak comparison testing of competing fuel containment systems has demonstrated a greatly reduced number of leak sources for the MCAIR sprayable sealant. Other major advantages of the MCAIR system over conventional bladders are increased fuel volume averaging (7%), lower weight (30% to 50%), and lower production cost.

CONCURRENT ENGINEERING

MCAIR implemented a concurrent engineering organization for the development of the night attack nose cone for the AV-8B. A work center concept was used to co-locate personnel from all disciplines in the design, production, and product support departments. Extensive use of computer aided design (CAD) on this program required design reviews to be performed using projection video equipment. CAD files were simultaneously viewed and discussed by the entire development team.

The teaming approach and the use of design reviews on CAD terminals eliminated the need for communicating technical data using engineering drawings. This resulted in a 40% savings in the engineering layout time.

CAD graphics data is used to prepare production planning documents. The production documents show exploded isometric views like those used in technical manuals. The production personnel find assembly information presented in this manner much more useful than traditional assembly drawings.

Savings achieved through the extensive use of CAD and concurrent engineering are significant. The production article for the nose cone was delivered five months ahead of schedule. This is attributed to a two-month span reduction for three dimensional layouts and a three month reduction for tool definition. This program also saw no tool rework, no part rework, and the virtual elimination of assembly fit-up problems. Design changes were reduced from six per drawing for the AV-8B to two tenths per drawing for the nose cone.

SOFTWARE FACTORY

Traditional methods of software development are very costly in an environment where avionics systems are growing in complexity and development schedules are being compressed. To counteract this, MCAIR assembled a team of software engineers in their software factory to develop automated software engineering tools. The computer-aided software engineering tools are being designed to meet the goals of improved productivity in software designs and to support both small and large software projects.

MCAIR's software factory uses a structured approach to develop software design tools that allow for upgrades to software in lieu of hardware redesign. In addition, the software factory's program achieves consistent documentation, diagramming, and traceability, allowing concurrent maintenance of software releases for several aircraft configurations.

The tools under development at the software factory reduce redundancy and minimize the repetitive work required by less sophisticated software development methods. The tools also help ensure that software design practices follow a disciplined and uniform process similar to proven hardware design practices.

MCAIR's software factory has evaluated existing commercial hardware and software packages to select the best fit to their requirements for customized software development tools. Software tools demonstrated to the BMP team included: menu driven tools for software interface definition; a structured analysis tool developed for the design of process and data flow diagrams; and a documentation tool with word processing and structured menus for software documentation. These tools illustrate the software factory philosophy of a generic environment that can be tailored to specific needs. The software factory improves productivity by providing an efficient user friendly software generating tool for aircraft avionics.

PRODUCT DESIGN DATA SYSTEM

The common thread necessary to integrate the many MCAIR groups involved in design and manufacturing is product definition data. Common data, in digital form, helps avoid errors and reduce costs in handling and interpretation of the data.

An internally developed Product Design Data System (PDDS) provides the digital data required for driving computer integrated manufacturing (CIM) efforts at MCAIR.

PDDS consists of CAD modeling specifications and applications software. The specifications and software are organized by component part classes such as: sheet metal, composites, fluids (tubing), and machined parts. The database structure for each part class was developed with emphasis on the CIM requirements peculiar to that class.

The PDDS procedures have been tested and refined on pilot aircraft programs including the F/A-18 leading edge extension and the AV-8B forward fuselage and crew station.

The MCAIR design for manufacture process is structured around an internally developed Computer Aided Design and Drafting (CADD) software package. The CADD application software is modularized based upon the particular part class. The design process is then further improved by incorporation of design rule decision trees and feature based capabilities within the software module for each part class.

DIGITAL PRODUCT MODEL

The Advanced Tactical Fighter (ATF) Digital Product Model (DPM) is an Air Force sponsored effort aimed at establishing methodologies to replace level three engineering drawings with electronic product data.

The technology being implemented includes:

* PDDI developed software schemas.
* PDES entities.
* Translators for converting CAD data at MCAIR and Northrop sites to IGES files and to text files on disk.
* Shared CAD database access between MCAIR and Northrop.

The DPM effort is demonstrating the construction, transportability, and applicability of digital product data.

PRODUCT DATA INTEGRATION AND STANDARDS

MCAIR has completed the Product Definition Data Interface (PDDI) program for the Air Force. The results from the PDDI program have been shared with the Product Data Exchange Standard (PDES) program. MCAIR further enhances the capabilities of PDDI through the use of the Initial Graphics Exchange Specification (IGES). They are very active in both national and international standards development groups. The Computer Graphics Metafile (CGM) standard is also supported and used to establish output device independence in the product support areas.

MCAIR has long been an advocate of the shared database concept. They have established data sharing and exchange with various plant sites, industry partners, and supporting contractors. A CIM technology transfer to the Naval Aviation Depot located at Cherry Point, North Carolina, resulted in a cloned version of the AV-8B CAD system at MCAIR, St. Louis. The Cherry Point local host central processing unit (CPU) is linked to finite element analysis software and the information management system which are both maintained in St. Louis. The CPU also hosts application software and a database on-site.

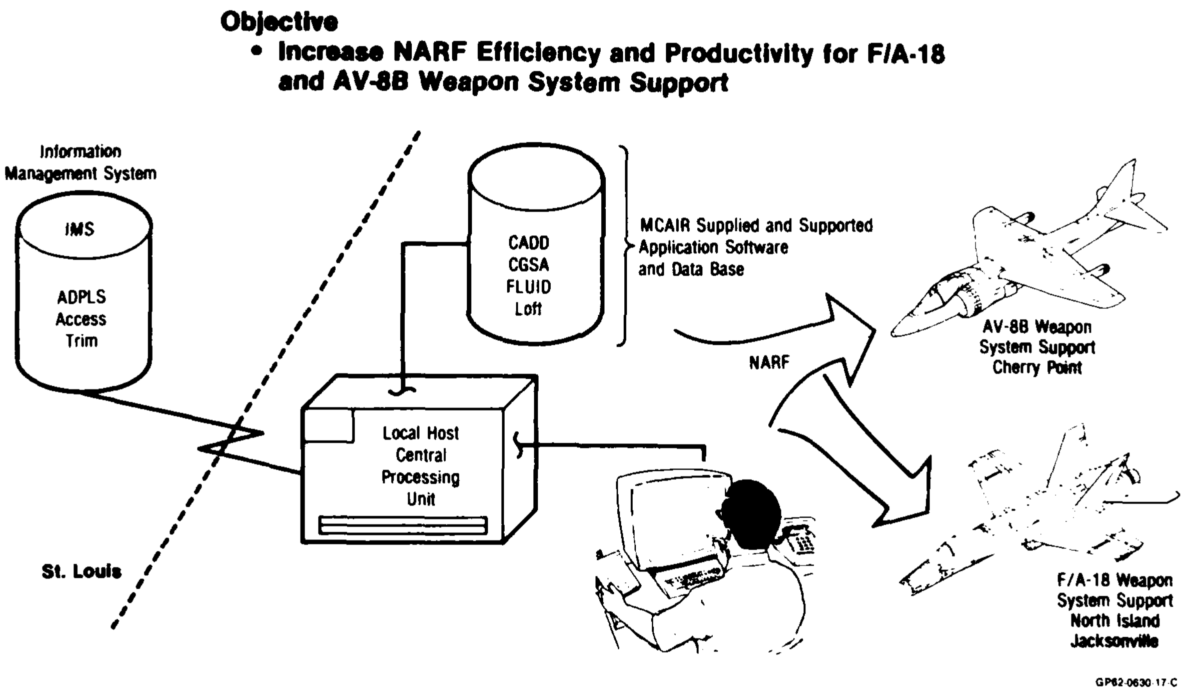

Figure 3.1-1: A CAD Technology Transfer to the Naval Aviation Depot

ELECTRONIC DEVELOPMENT FIXTURE

The 3D design process eliminates the need to create a physical mockup. The Electronic Development Fixture (EDF) approach addresses sheet metal, composites, electrical wire bundles, tubing, tooling, and fastener locations. A 3D engineering digital data definition is transferred and used for manufacturing. Artificial intelligence (AI) has been embedded in the software to enhance producibility in the sheet metal, tubing, and electrical wire bundle areas. The AI imposes certain design constraints such as minimum bend radius as a function of hydraulic tubing ID and minimum clearance for connectors on wiring harnesses.

Electrical wire bundle manufacturing has been enhanced by using software to convert the 3D definition of the wire harness to a flat pattern for fabrication purposes. The flat patterns generated by this method are more accurate than the patterns that were previously generated by the manual method.

The EDF allows the design of a major subassembly to be coordinated between and within design groups by subdividing the assembly into zones. The zoned compartment approach is then used to develop the design through an iterative process with built-in manufacturing constraints. The design is iterated from an initial "best guess" configuration into the final design.

An analysis of two pilot programs indicates that use of a 3D database versus a 2D database reduced design changes by approximately 50% and reduced the production item release schedule by six months.

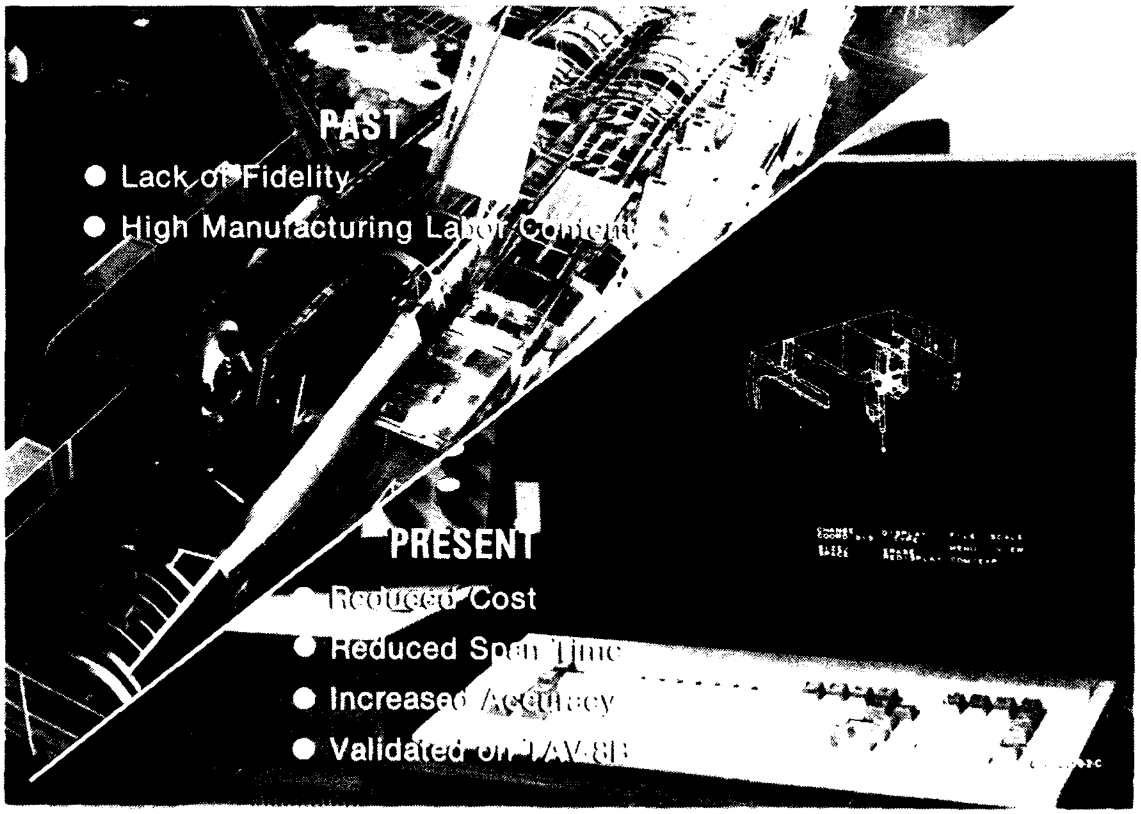

Figure 3.1-2: The EDF Eliminates the Need to Create a Physical Mock-Up

PARAMETRIC EVALUATION OF LOFT AND SURFACE DATA

MCAIR has developed a method for using loft and surface data created on incompatible CAD systems with no loss of definition or accuracy. This is accomplished by using a software module known as a parametric evaluator that standardizes the mathematical representation of all curves and surfaces. Mathematical operations on geometry, such as surfaces and surface intersections, are performed on one standard representation regardless of the CAD system. The standardization provided by the parametric evaluator allows the confident sharing of complex and critical geometry.

ADVANCED DESIGN WORKSTATION

MCAIR has developed a CAD environment specifically for the purpose of assisting engineers in designing, sizing, and evaluating aircraft concepts. The system aids the designer in concept formulation by helping compile data on operational requirements, aerodynamics, propulsion, structure, design ground rules, weapons, and subsystems. A general arrangement for the aircraft is developed using this system. The configuration for the aircraft is evaluated against mission requirements for performance and sizing of the aircraft. The model of the concept vehicle is parametrically scaled within defined design rules to meet the mission requirements.

ELECTRICAL SYSTEM DESIGN

Three programs are being used for electrical system design. Automatic Control and Checking for Electrical Systems Support (ACCESS) is an older database that has collected and controlled information for electrical wiring harnesses. This program is being improved to reduce duplication of data and to coordinate and extract data from engineering sources.

The CADD wire module, integrated to ACCESS, adds some functional intelligence such as automatic parity check, automatic path length calculations, interactive updates from CADD, and a wire pattern output.

The Common Electrical/Electronic Data System (CEEDS) is being developed to provide a truly integrated, intelligent, and interactive data system. Functions included in CEEDS are: schematic capture, a link from ACCESS to Computer Aided Technical Illustration (CATI) to eliminate the need to enter data into both systems, and a capability to transfer parts list data from the ACCESS database into the CATI schematic 2D drawings.

AUTOMATED FORGING DESIGN

MCAIR has invested over 25 man-years in the development of an automated forging design program. The program was initiated in 1979 and consists primarily of software written in Pascal that operates on the MCAIR CADD system. The input to the automated forging design software includes forging type, material, draft angle, forging plane, axis system, parting line, and machined part configuration. Output consists of a 3D wireframe model that can be transferred to forging vendors by magnetic tape in the IGES format.

Historically, when MCAIR has relied upon forging vendors to design forgings based on machined part geometry, numerous (a minimum of three) vendor bids would be received that would require MCAIR technical evaluation. This was a lengthy and costly process. By performing forging designs in-house, vendor quotes need only be reviewed by MCAIR based on cost, schedule, and previous experience. Additionally, by automating the forging design process, 90% savings in design time and 30% reductions in vendor lead time are realized. Vendor tooling costs are also reduced.

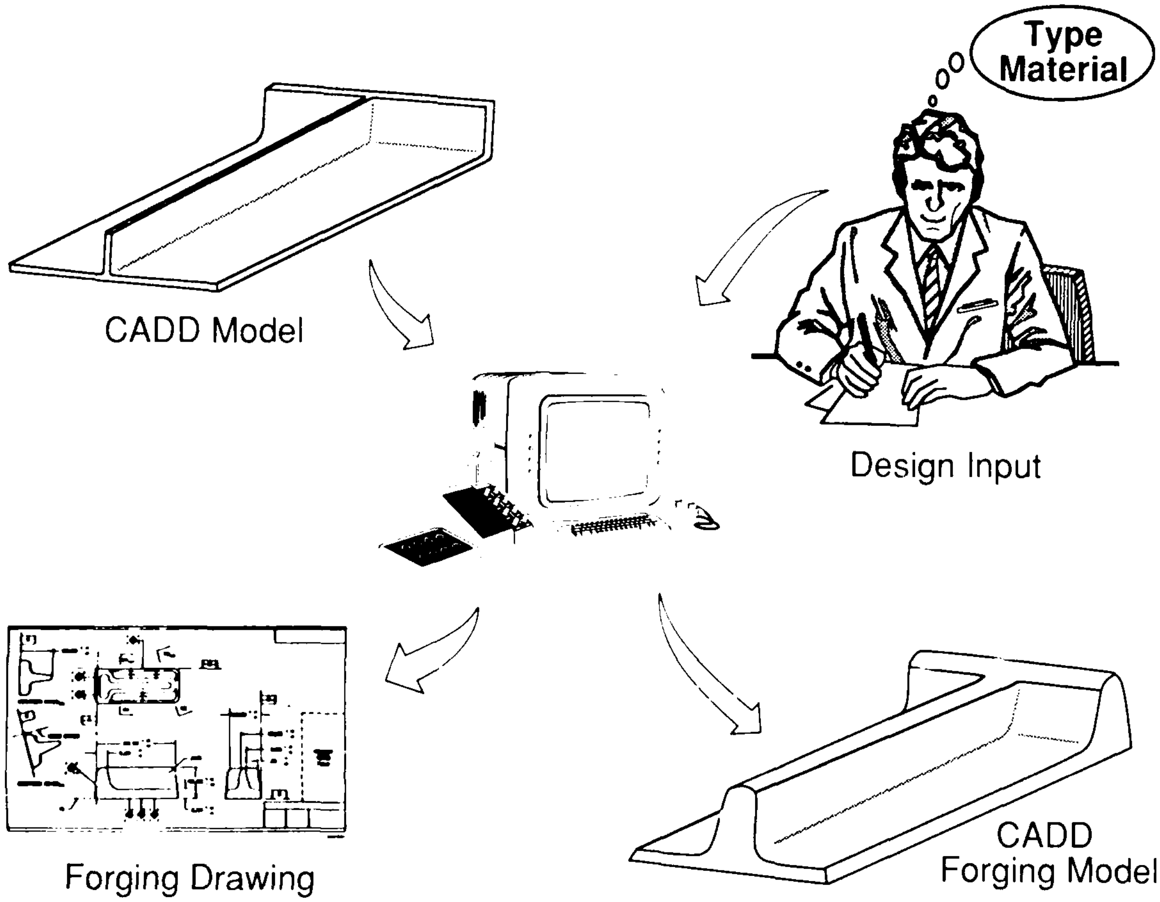

Figure 3.1-3: Automated Forging Design Reduces Design Time and Vendor Lead Times

AIRCRAFT FASTENER SELECTION SYSTEM

The Aircraft Fastener Selection System (AFSS) assists designers in the complex process of choosing the correct assembly fastener, given the design parameters of an aircraft. Although the use of fasteners is significantly reduced in newer aircraft design, their use in current aircraft still numbers in the hundreds of thousands.

The AFSS has been integrated into MCAIR's CADD system, where a designer may execute the expert system by pressing a CADD function key while working on a part design. The designer is then led through a series of questions on the intended use of the fastener. The knowledge base for fastener selection includes fastener usage policy, the design handbook, the standard parts manual, structures handbooks, previous design documents, and expert designers. When the proper fastener is selected, the designer can return to CADD and display the part with the fastener callout added, and then continue with the CADD session.

The use of this expert system provides additional benefits in compliance with producibility and manufacturing constraints, compliance with supportability requirements, and the preservation of corporate production knowledge.

AUTOMATED FINISH SELECTION ADVISOR

The Automated Finish Selection Advisor (AFSA) assists in the selection of coating requirements for aircraft parts. Various coatings for finishes must be applied to aircraft parts for corrosion protection, camouflage, or other functional purposes. The finish advisor is helpful because of the large number of parts, the numerous material types, and the varying purposes of coating systems.

The AFSA has been implemented to assist the production engineer in the correct interpretation of the finish specification requirements. AFSA provides a section for the selection of the finishing and sealing requirements by contractual codes and contains a catalog which outputs proper finishing treatments and specifications for each code. The operations associated with these codes are performed to MCAIR specifications and referenced military specifications. AFSA also provides related production planning, manufacturing, and quality assurance notes, which makes the system useful to these groups as well as to engineering.

The use of AFSA provides benefits in that it reduces the production engineering workload and the production planning workload and provides for the standardization of finishes while incorporating lessons learned.

MODULAR SIX DEGREE OF FREEDOM ANALYSIS PROGRAM

The modular six degree of freedom (SDF) analysis program used as an integrated resource with a shared database has resulted in significant benefits. Prior to SDF, many of the engineering areas had their own programs that were not compatible or accessible to other engineering areas. The integrated modular approach has brought better analysis capability to the engineering staff working on flight control system design, weapons system separation, ground handling, accident investigation, carrier suitability, and maneuver load analysis. Interactive with the SDF program are aerodynamics, loads, weights, propulsion, guidance and control, and simulator data and analyses.

Sharing this computing capability and database has improved communications between engineering departments through the use of common code and common data models. It has produced consistent results eliminating verification tasks, and has maintained an up-to-date configuration database for the engineering departments. The processing is performed on one of the MCAIR mainframe computers and has a well designed and user-friendly interactive structure. The modular SDF approach has clearly reduced engineering time and cost for design and trade-off studies for component selection, for weapon system and mission adaptive development, and in the resolution of performance and handling problems.

INTEGRATED STRUCTURAL ANALYSIS PACKAGE

The Integrated Structural Analysis Package (ISAP) is an integrated system containing all functions needed to perform detailed stress analysis appropriate to aircraft structures in a fully digital environment. This system represents a significant technology transfer to the AV-8B program. The system was integrated and installed under a Naval Depot contract and went on-line at Cherry Point in September 1988.

A computer graphics user interface supports the full range of functions in the ISAP system, effectively providing a single form of access to analysis tools, stored data management and display functions, graphics construction, and document preparation. The range of geometric shapes covered under the parametric definition functions run from simple to complex, including composite-type structures. Extensive database management capabilities eliminate the need for data look-up and allow for the orderly storage of analysis documents.

ISAP forms one-third of a triad of systems that support stress and fracture mechanics analysis in a fully digital aircraft design environment. The integrated system uses CADD generated aircraft geometry and parametric definition for parts to be analyzed. Internal loads are drawn from the Computer Graphics Structural Analysis (CGSA) system.

COMPUTER GRAPHICS STRUCTURAL ANALYSIS

The Computer Graphics Structural Analysis (CGSA) system provides a flexible means to build and manage finite element models for structural analysis. Geometry from the CADD or Unigraphics CAD systems forms the basis for analysis models. Mesh generation and editing are automated in this system. Full aircraft finite element model and free-body analysis functions interface to external solvers, including MacNeal Schwendler Corporation-NASA Computer Program for Structural Analysis (MSC-NASTRAN), to provide internal loads solutions for complex structures. Large vehicle structures are managed as assemblies of smaller substructures.

New P-convergence methods and super-elements (solids) are supported in this system, which greatly reduces modeling time and improves accuracy of analysis of complex objects. Estimation of probable analysis errors contributes to improvements in accuracy and efficiency in the analysis process.

CGSA provides extensive data management functions for analysis loads and constraints and answers display functions including color contour plots. Minimal modeling effort and minimized disk storage requirements are significant system characteristics.

EXPERIMENTAL MODAL ANALYSIS

Modal analysis techniques are used to define, measure, and analyze the response of airframe structures in vibration environments. Undesirable effects of vibration in air vehicles include accelerated structural fatigue damage, avionics systems failures, and flutter. These adversely impact the performance of the vehicle through degradation of systems functions, degraded flight characteristics, or restrictions on the flight envelope. Corrective measures are determined by analysis and experimental testing, in which modal analysis techniques play a significant role. Application of these techniques throughout the full scale development cycle results in improved structural design and vehicle performance.

Measurement of the response includes definition of resonant frequencies and structural deflection at those frequencies along with damping value measurements. Excitation is applied to the structure analytically through a defined forcing function or experimentally through controlled external excitation forces. Analytically, the information is acquired through finite element modeling and experimentally through use of real-time Fourier analyzers. Integration of both the analytical and experimental results has been accomplished so that the result of both can be compared. MCAIR's laboratory computer network allows access to this information by analysts and laboratory engineers and their analytical systems.

AUTOMATED MASS PROPERTIES SYSTEM

MCAIR has developed and applied the Automated Mass Properties System (AMPS) to two variations of its design process. In both cases, the purpose was cost reduction and improvement in accuracy over what had been largely manual calculations.

The first application of AMPS is centered around the MCAIR CADD software. AMPS utilizes existing CADD wireframe models for calculation of properties such as mass, weight, center of gravity, and moments of inertia. AMPS allows projection and rotational sweeps of boundary geometry as well as volume cut and sum methods of mass property generation. AMPS, within CADD, is also integrated with the Interactive Weight Accounting Program (IWAP).

The second application of AMPS is based on MDC Unigraphics CAD system. The Unigraphics implementation of AMPS differs from that of CADD in two ways. The first difference is in the treatment of volumes. This version of AMPS creates a fully surface bounded model from the wireframe model. The complete surface with addition of surface normal data allows direct mass property calculations more accurate than the previous cut and sum method. The second difference is that this AMPS variation does not yet support IWAP.

The two AMPS implementations have allowed MCAIR to reduce costs and manning levels by approximately 50%. AMPS has also provided improved feedback of potential aircraft weight problems to the design group.

COMPUTATIONAL FLUID DYNAMICS

Powerful analysis tools based on Computational Fluid Dynamics (CFD) technology are now entering the engineering design process. These tools are changing the methods by which fighter aircraft are designed. Compared with wind tunnel testing, CFD analysis offers two key advantages.

* A complete description of the flowfield is obtained so that all interactions can be studied.
* Data can be acquired in days rather than months allowing rapid optimization of geometries.

Flowfield interactions between vehicle components can strongly affect performance, and these interactions cannot be predicted with simple analyses. Cases requiring advanced analysis include viscous flow, vortices, shock waves, and unsteady flow. Solutions to Euler and Navier-Stokes equations can improve effectiveness of subsequent tests and can increase innovation.

Speed ranges that can be studied include conventional flight regimes, high speed, and hypersonic speeds. MCAIR's goals for internal CFD technology are to develop standardized methods for non-specialists, develop a limited number of multi-purpose analysis codes, and use common data formats wherever possible.

In MCAIR's implementation of CFD tools, geometry can be drawn from a variety of sources including the CAD systems of MCAIR and its teaming partners, commerical CAD systems including CATIA and Unigraphics I & II, PATRAN, IGES files, and point or paneled models defining aerodynamic shapes.

CREW SYSTEM DESIGN ANALYSIS TOOLS

MCAIR has utilized third party software for simulation of flight crew during escape, crash, or flight maneuvers, in combination with internally developed software for crew station geometry and graphics. This software has been used effectively to evaluate and optimize design of crew control and escape systems. It accounts for six degrees of freedom dynamic loads and an extensive range of variables such as wind loads, velocity, ejection thrust, vibration, heat, and for typical human ability to reach, move, and exert force with arms and legs.

MCAIR plans to validate computer simulation results with flight test and escape system rocket sled tests in 1989. An extension of the software to a two-person crew is under development. 3D graphics animation is very effective in this application.

STORES SEPARATION ANALYSIS

Stores separation has been simulated by using wind tunnel measurement data in conjunction with six degrees of freedom analysis. Results are graphically displayed with 3D animation.

The Stores Separation Investigation Package (SSIP) consists of three programs: Time History Animation Display (THAD); Collision Separation Distance Calculation (COLLIDE) program - a program to determine minimum separation distances between store and aircraft; and Stores Separation Distance Display (SEESEP), which displays a step-wise detail of a store separation. Use of these programs aids the engineer in evaluation and understanding of the store separation characteristics.

Once the wind tunnel data has been adequately established, it is possible to induce design variables and verify the store separation more adequately prior to flight test. These programs can be used interactively with a host computer with a well designed structure and user interface.

TURNAROUND AND RECONFIGURATION SIMULATION

Turnaround and Reconfiguration Simulation (TARS) is a MCAIR contractual effort administered by the Air Force Human Resources Laboratory at Wright-Patterson Air Force Base. This effort employs the MCAIR CADD system, augmented by animation and simulation software, to electronically portray maintenance operations on the F-15E. The simulation includes the movement of ordnance and weapons racks to the aircraft while it is parked in a confined blast shelter. Results demonstrated a capability to simulate turnaround and reconfiguration tasks before the first flight of the F-15E. Human factors and collison detection information generated by the simulation prompted changes to F-15E technical data.

TARS is being used to examine maintenance scenarios on advanced programs which will benefit from:

* The elimination of on-site turnaround demonstrations.
* Fewer design changes.
* Improved support planning.
* Improved training.

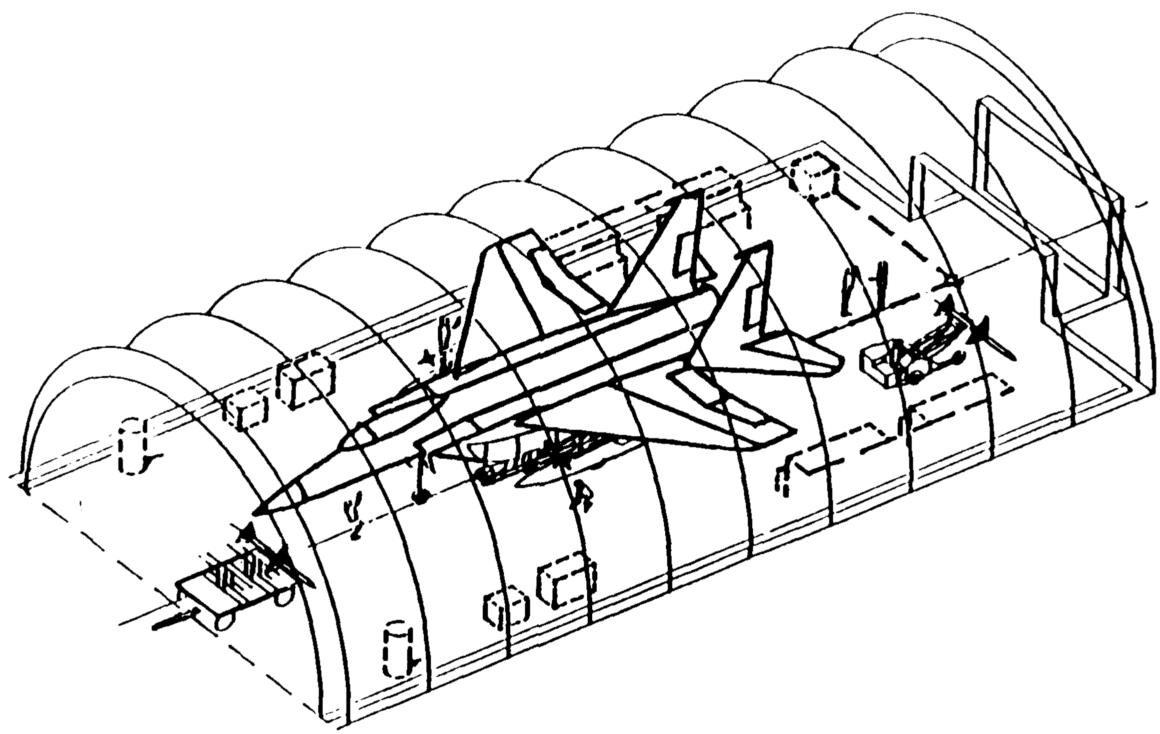

Figure 3.1-4: Animation and Simulation Portray Maintenance Operations and Reconfiguration Tasks for the F-15E

ENGINEERING DATA CONTROL

MCAIR utilizes automated methods and a central database to control and track engineering drawings, parts lists, and administrative data.

The Automated Drawing Parts List System (ADPLS) provides a central drawing and parts database for each product. The ADPLS allows tracking of drawing and part changes as well as release dates. The ADPLS database is up-loaded in an overnight batch process to the mainframe based information management system. The central database may then be accessed for planning, manufacturing, and support applications.

The Engineering Automated Release and Record System (EARRS) provides the capabilities of ADPLS, but for administrative data rather than drawings and parts. EARRS allows release and tracking of drawing numbers, design releases, release status, and product history. EARRS supports a large number of standardized reports as well as flexible reporting formats. It also allows control, reporting, and tracking of superceded parts.

3.2 TEST

LABORATORY COMPUTER NETWORK

The laboratory computer network is one local area network (LAN) segment of the MDC Metropolitan Transport Network (MTN). The MTN has similar hubs for many other local area networks throughout the company facilities.

The laboratory LAN is presently installed in all major laboratory facilities and allows high speed data interchange between the testing laboratory and the requesting department. Through this LAN, set-up information can be transferred prior to testing. Test control and monitoring can be accomplished from remote locations, and test results are immediately available to users. The laboratory application of the network also allows the review of preliminary test request documents, the transfer of pre-test data in the form of geometry and load spectrums, and the interchange of reports and status information between the specific laboratory and the using department.

This network also provides access to plant level systems and office automation (electronic mail) tools through gateways to the IBM mainframes used throughout the company.

CONTROL DYNAMICS LABORATORY

The MCAIR Control Dynamics Laboratory has constructed a test fixture known as the "Iron Bird". This steel structure is used to conduct a variety of test programs on aircraft hydraulic and flight control systems. Actual flight worthy hydraulic systems and flight control actuators are exercised under controlled conditions in response to inputs from flight control computers installed on test benches. This system is used for initial component development, system development, and test. It is also used to solve problems which develop in mature systems.

A unique feature of the F-15 Iron Bird is that it is presently configured to support both F-15E and Short Take-Off and Landing (STOL)/Maneuvering Technology Demonstration Programs. A series of manual valves are used to connect system unique components to the hydraulic system. Flight controls, flight control computers, and data acquisition systems are located in adjacent rooms. The ease of transition permits different configurations to be run on successive shifts.

WIND TUNNEL MEASUREMENT TECHNIQUE

The need for improved quality and greater efficiency in wind tunnel test measurement techniques provided the impetus for MCAIR to develop three new methods of testing. These improved test methods provide for faster, more accurate measurement of the wind tunnel model's position and pressure points. They also provide for an automated strain gage balance calibration system.

The model position measurement system utilizes a polarized light sensor mounted into the airframe model that allows for very accurate on-board pitch angle measurement. This simple and ruggedized method precludes the necessity of providing offset weights and corrective mechanical measurements to the mounting fixture utilized to suspend the airframe model in the wind tunnel.

The electronic pressure scanning system consists of several very small and lightweight multichannel electronic pressure transducers, which can provide up to 1,024 channels of pressure. These pressure channels are connected to a microcomputer. This portable stand-alone system provides for acquisition of multiple data channels with real-time data display capability.

The wind tunnel automatic balance calibration system allows for faster and safer calibration of the strain gage balance which is used to measure the deflection loading of the airframe models. The strain gage balance is attached to the suspension arm that supports the airframe model during a wind tunnel test. The calibration of the balance is now accomplished with an automated fixture that provides the proper application of calibration loads and electronic locking. The loading of the strain gage balance is performed by a hydraulic cylinder in a computer controlled fixture. This allows the calibration of six component balances over multiple load ranges and allows the calibration of balances with varying diameters. The fixture eliminates the need for the manual application of heavy weights and for manual leveling. Calibration time is reduced and quick calibration comparisons can be made via the test processing software.

WIND TUNNEL DATA SYSTEM

The Wind Tunnel Data System (WTDS) gathers, manages, analyzes, and displays the results of wind tunnel testing. Volumes of wind tunnel data may be displayed and analyzed quickly resulting in time and cost reductions. Test data is analyzed on-site prior to the next run of a wind tunnel test. WTDS is used as a tool to diagnose suspected data problems. Run-to-run and test-to-test comparisons of test variables are provided. Report quality plots are generated.

On-line users include laboratory test engineers, aircraft project engineers, data acquisition engineers, and wind tunnel operators. MCAIR's wind tunnel facilities (polysonic, low and mini-speed, mass flow claibration, and nozzle thrust test stand) are on-line to the WTDS.

TESTING OF DISPLAYS SYSTEM COMPONENTS

MCAIR developed a new integrated cockpit displays test system for the F-15E fighter program. Initial design criteria emphasized maximum testability and throughput while minimizing cost.

"Hot mock-up" integrated testing is generally accepted to be the ultimate test of performance and compatibility. Typical hot mock-up systems are relatively inflexible, expensive, and only provide moderate throughput. Stand alone testers have high throughput and provide almost unlimited flexibility in parametric testing, but often fail to detect subtle incompatibilities between the various display system components which show up when these units are installed on an aircraft.

The F-15E Displays Test System consists of five substations and a central controller. The test system is unique in that it is a dual purpose, multi-functional test system permitting the simultaneous testing of individual units of the F-15E displays system or the testing of any number of the units in an integrated (hot mock-up) mode.

The new system provides both capabilities in a single test system through the implementation of solid state switching. This approach eliminates the need for dedicated bench test units by using production display units which are first tested, repaired, and calibrated in the stand alone mode, then are connected through solid state switching to other system units for final verification of system operation. This system has very high throughput and allows any combination of displays units to be connected to the Multi-Purpose Display Processor with other display devices under test in the stand alone mode.

3.3 PRODUCTION

ADVANCED GROUP TECHNOLOGY SYSTEM

The Advanced Group Technology System (AGTS) utilizes an internally developed classification and coding scheme based on 32 attributes to identify the similarities of machined parts.

Once the parts have been coded, the information is stored into the AGTS relational database. User defined part families are formed based on similar attributes. This allows retrieval of similar parts and an analysis of the manufacturing processes and routings. AGTS gathers data needed for cell design. It facilitates the adding of new parts to existing cells by selecting and ranking the machines required to manufacture a particular part. It provides cost justification for the purchase of capital equipment and for the formation of additional cells. It also supports the reduction of work-in-process inventory and optimizes machine utilization.

The software is written in FORTRAN and OPS-5. A VAX 11/780 is used with an Oracle database. Procurement of a VAX 3500 for the system's database and VAX 2000 workstations in the near future will supply the hardware necessary to introduce the system in a pilot production mode to the machine shop during the fourth quarter of 1989.

SIMULATION FOR PRODUCTION OPERATIONS

MCAIR uses simulation to aid management in projecting manpower and equipment requirements. By modeling complex manufacturing systems, planners can observe the effects of changes over time and evaluate "what if" scenarios. This analysis significantly reduces the technical risk of implementing changes.

A PC-based simulation program called WITNESS obtained from ISTEL Corporation of Boston, Massachusettes, is used. It incorporates animation and model design capabilities that reduce the amount of simulation coding. Tool planners and other users actively participate in the design of the simulation model. This minimizes the time needed to develop and modify models and produces the most effective results. Reports and plots generated by the program allow the planners to identify bottlenecks and to smooth out the flow of work.

Current applications include developing a model for evaluating part flow for a proposed K&T five axis machining cell and a model of a cutter grinder cell. A recently completed model evaluated the production capacity of a Gerber cutting cell. MCAIR also uses WITNESS to develop the assembly operations for the production of a new weapons program. The package makes use of a color graphics display, which quickly highlights potential production bottlenecks as well as under-used tools.

MCAIR feels that the system has been effective in their planning for the A-12 program. It has allowed them to review the impact of various schedules and engineering change proposals. Simulation is also a very effective technique for testing many different shop loading strategies.

LARGE ORDER ASSEMBLY PLANNING SYSTEM

MCAIR is implementing a planning system for manufacturing major assemblies called Large Order Assembly Planning System (LOAPS). It is a group of computer based routines and electronic interfaces that provide the capability to assimilate, store, and generate production planning information required to build major aircraft assemblies. Information from all major assembly planning activities is captured and processed to generate work instructions such as part and tool lists and operation sequence data. This information will be combined with graphic aids and then disseminated to the shop floor. When fully implemented by the end of 1989, MCAIR projects a 66% reduction in planning cycle time.

GENERATIVE PROCESS PLANNING SYSTEM

The Generative Process Planning System (GPPS) is a rule based, expert system used to automatically generate complete process plans. It incorporates, in the form of "if-then" instructions, the best practices and knowledge of master planners, industrial engineers, and quality control experts. Because it incorporates the knowledge of company experts, new planners with only a basic understanding of engineering data can generate process plans for 85% of the parts produced at MCAIR.

The GPPS makes use of the IBM Time Sharing Option (TSO) system. It has been implemented in generating the process plans for tubing, electrical assembly, composites, and sheet metal parts. MCAIR is currently expanding GPPS to include planning for conventional and NC machine planning.

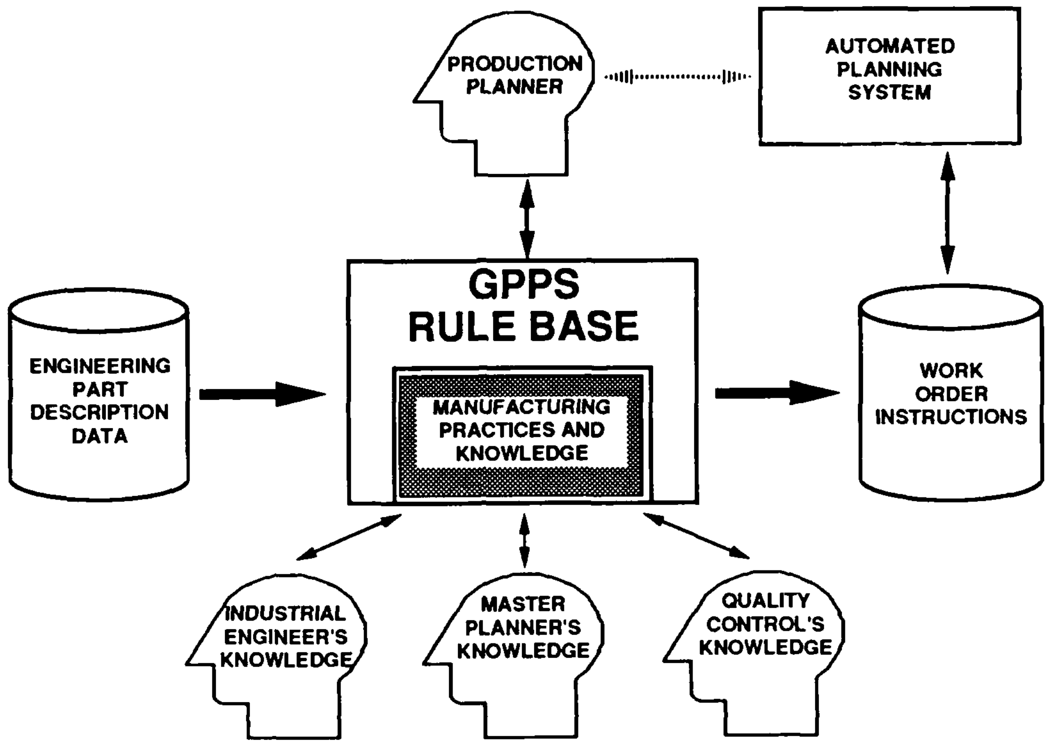

Figure 3.3-1: GPPS Incorporates the Knowledge of Company Experts in the Generation of Process Plans

BAR CODES

MCAIR utilizes bar codes in a wide range of data entry and collection applications. Bar codes are found on materials, parts, work orders, tooling, capital equipment, and employee badges.

MCAIR's Integrated Composites Center (ICC) has bar code readers on all fixed workstations and portable terminals. Bar codes are used to track composite materials, parts, and tools throughout the manufacturing process. ICC also uses bar codes for other purposes such as access to computer systems and electronic signatures.

The availability of faster and more accurate hand held readers and database interfaces makes bar code a cost effective and efficient means of data entry. Data entry rates are ten times faster than manual entry and resultant error rates are 1 in 3,000,000 characters versus 1 in 300 for manual data entry.

MDC is active in promoting bar code standardization. It publishes the MDC Bar Code Report and has established the MDC Bar Code Advisory Group. It is also active in the Federation of Automated Coding Technologies (FACT) and is promoting the development of an American National Standards Institute (ANSI) standard for bar codes.

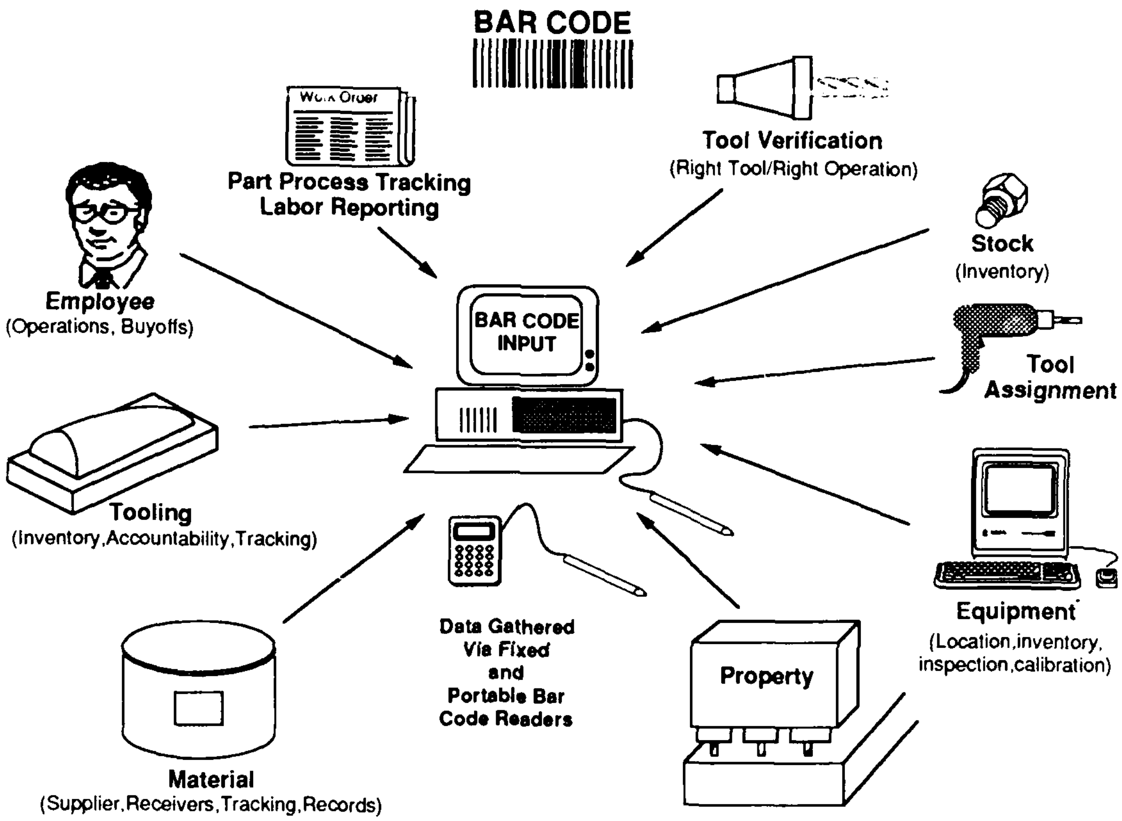

Figure 3.3-2: Bar Codes are Utilized in a Wide Range of Data Entry and Collection Applications

PARTS CONTROL SYSTEM

The Parts Control System (PCS), implemented in 1987, is an on-line, real-time control system. Its primary function is to provide accurate and timely status of parts in process. It provides notification of exception conditions to management and captures the history of all parts manufactured by MCAIR.

On-line retrievals and updates are possible. These include current status and location of work in-process, priority of assigned work, work center, workload, part history and inventory, and major assembly and detailed work order information. PCS interfaces with sixteen support systems.

Since its implementation, PCS has been providing timely and accurate information to management and has reduced the response time for exception notifications from days to minutes.

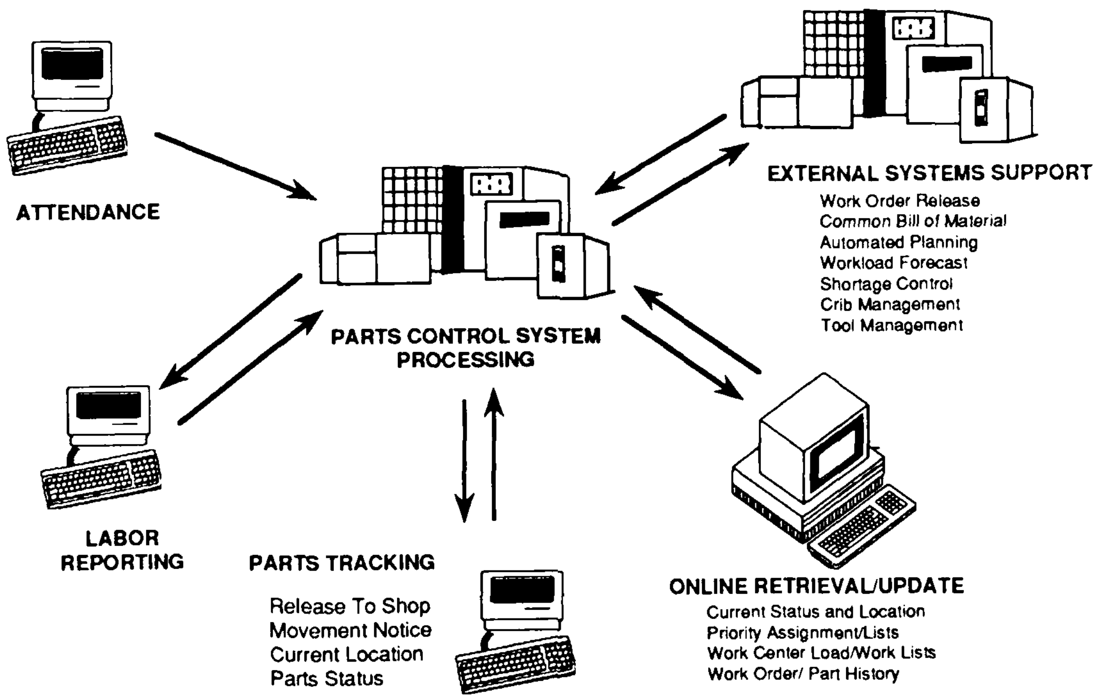

Figure 3.3-3: PCS is a Real-Time Control System Interfacing with Several Other Support Systems

PREFERRED SUPPLIER QUALITY TEAM

MCAIR has embarked on a program to certify suppliers as meeting quality and delivery standards. Based on a quality and delivery rating, suppliers would be authorized to ship with no formal receiving inspection or government source inspection.

MCAIR evaluates quality based on both numbers of defects and seriousness. On time delivery is evaluated. If a supplier meets MCAIR standards, a quality audit is performed at the supplier's location. The results are reviewed by all involved departments and by the Naval Plant Representative Office. Certification is given by part number only. No blanket approval is issued.

Suppliers must follow certain guidelines to stay approved. The supplier selects a quality control (QC) representative, who is issued the QC stamp. He must establish an internal audit system and a statistical process control (SPC) system and show continuing improvement.

MCAIR will perform random receiving inspections, issue a monthly rating review, and a quarterly SPC report. MCAIR will also perform an annual audit. To-date, 22 suppliers are certified and 20 are being evaluated.

AUTOMATED PLANNING FOR RECEIVING INSPECTION

Automated planning for receiving inspection is a computer aided management system designed to provide standardized, reliable inspection criteria. Inspection requirements for incoming parts and materials can be created and printed by the system. Additionally, the system produces essential reports for visual access maintainability, daily effort levels, and manpower forecasts.

The system also interfaces with the purchase order system, allowing newly purchased items to be simultaneously added to the purchase order database and the planning part number database. With this information, a program will search by part number for predetermined quality planning indicators that can be used for receiving inspection. These automated planning files are updated in a daily batch process as inspection sampling level adjustments are made within the Supplier Evaluation Program. Supplier furnished items may not enter the receiving cycle without predetermination of inspection requirements by quality planning.

The automated planning system provides the flexibility to create and maintain receiving inspection plans within a work center, thus decentralizing the receiving activities and eliminating the need for multiple file systems and dispersing personnel. Shipments received at a decentralized receiving area which require quality planning determination can be handled through an electronic link.

QUALITY INTERPRETATION CENTER

The Quality Interpretation Center (QUIC) is a central off-line digital interpretation and storage system for non-destructive test (NDT) data. It was developed by MCAIR to streamline ultrasonic NDT interpretation. It has resulted in an improvement in NDT equipment utilization from 34% to 60%. This improvement represents the equivalent output of two automated ultrasonic scanning systems.

In interpreting the data, QUIC sequentially displays frames of data to be accepted or rejected. The status of each data frame is recorded and a graphic display illustrates which frames of the part have been inspected. If desired, frames of data, complete with operator inserted explanations or annotations, can be plotted. All operator interaction is through a touch screen or mouse with integrated display that has been designed for use by a technician or non-computer type. When interpretation is complete, the part's data file, complete with the frame's status and any graphic annotations, can be archived to either magnetic tape or optical disks.

AUTOMATED ULTRASONIC SCANNING SYSTEM V

The Automated Ultrasonic Scanning System V (AUSS V) is a computer controlled ultrasonic scanning, squirter system designed to meet industry's inspection demands for highly curved composite, metallic, and composite/metallic assemblies. The system, which was developed by MCAIR, has resulted in the reduction of inspection time, reduction of tooling costs, one-to-one flaw sizing, and improved data presentation. Parts currently requiring multi-segment scanning (up to 40 segments) can be completed in a single scan with the AUSS V. Nine axes of motion enable the unit to accurately follow a complex curvature without part repositioning. Through transmission and pulse-echo, data can be collected simultaneously during scanning of curved assemblies due to accurate curve following. The system uses digital data imaging.

Additional features of the AUSS V are:

* Conversion of 3D to 2D data, which provides for accurate location of anomalies in actual surface distance measurements.
* XYZ space part description allows complex scan paths to be calculated without machine axis dependence. This results in fast, efficient scanning of complex surfaces.
* Manual teach capability.
* CAD/CAM part configuration interface.
* Imaging in 8 to 256 colors or gray shades.
* Optical disc storage.
* Vector and alphanumeric overlay annotations that can be stored with the data or on hard copy.

MDC is currently marketing the AUSS V and has sold systems to two major aerospace companies.

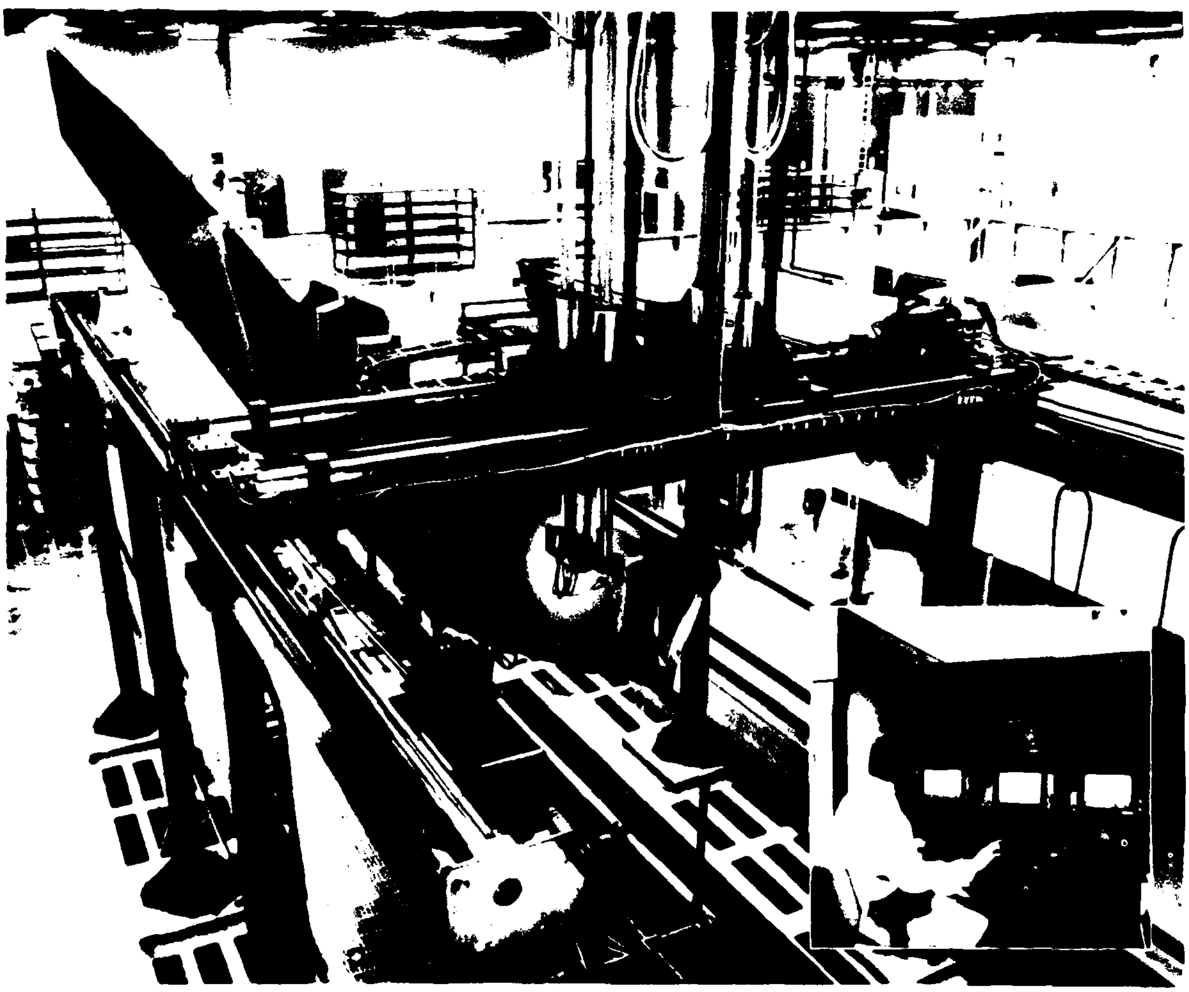

Figure 3.3-4: AUSS V Uses Digital Data Imaging to Inspect an AV-8B Composite Wingskin

TRAINABLE GOODNESS FILTER

The Trainable Goodness Filter is an AI application being developed to simplify the interpretation of NDT data. It uses Novelty Detection neural network technology to compare ultrasonic inspection data from a test part to data from a known good part in order to find differences which may be due to defects. The visual output of the system will be part defects only. The system will reduce interpretation time and automate the volume of ultrasonic scanning system data. In the future, the system will use defect history to establish a defect classification system that will track trends.

X-RAY TECHNIQUE GENERATOR

The X-ray Technique Generator is an expert system that incorporates existing X-ray technician expertise in the fonn of rule-of-thumb, process specification requirements, and X-ray system limits. The objectives of the system are to provide consistent X-ray techniques, to reduce the time required to generate a preliminary technique (from 4-12 hours to 2-4 hours), and to provide preliminary techniques that are more likely to work on the first try.

The system prompts the user for information (part dimensions, thicknesses, material, etc.) about the part in order to generate the preliminary technique. To date, a prototype generator has been completed and tested against an expert human with good results. It is capable of preparing techniques for doors with hats, channels, rails, and angles.

The system will be implemented in the near future in a pilot production mode, and will be incorporated into the Integrated Composites Center. MCAIR also plans to expand its expert system capability to include other NDT test methods.

AUTOMATED TOOLING ORDER SYSTEM

The Automated Tooling Order (ATO) system is a communication link between the five major user groups involved in the planning of tool orders. ATO serves as a medium by which the Planning, Tool Design, Tool Control, Scheduling, and Tool Crib groups can input their needs for tools and determine when those tools will be available.

The ATO system contains specific information about the tool, instructions on how to make the tool, tool family relationships, and history of the tool order development cycle. This includes both perishable tools (less than one year service life) and contract tools (greater than one year service life and associated with a specific contract).

ATO makes possible the tracking of tooling orders through the development cycle by allowing any of the user groups to query the system at any time. ATO uses standard tooling instructions and automatically updates MCAIR's Special Tool Accountability, Fabrication, and Storage (STAFS) system and Tool Crib Management system when tool orders are approved.

The time to generate a tooling order has been reduced from an average of 11 days down to four. ATO also has the capability to provide one day tool order generation. Mass paper movement and lost tooling orders have been eliminated, and tooling errors have been reduced. ATO has provided managers with a greater visibility of the work in their areas, as every tool order includes the operator's name and the date and time the tool was requested. Approximately ten man-years have been saved to date as a result of the ATO.

PITOT STATIC AIR PRESSURE REGULATORS

Pitot static air pressure regulators are used to simulate altitude and air speed during ground tests of air data sensing systems. These regulators have had deficiencies which made them either unreliable or detrimental to the aircraft systems to which they were connected. MCAIR has designed and built an advanced pitot/static air pressure (AP/SAP) regulator which satisfies the requirements of production flight line testing of the air data sensing systems on the F-15, F/A-18, and AV-8B aircraft.

The unit is completely self contained with vacuum and pressure pumps and an electronic control unit. Only 120V AC 60 HZ power and the appropriate connecting hoses are necessary. It is mounted in a small roll-around cabinet on semi-pneumatic tires. The regulator is microprocessor controlled with all software resident in the unit. Operator interface is through a hand held terminal with a key pad and liquid crystal display. The terminal can be operated from the cockpit allowing one operator to perform all functions of the test.

Programmed procedures, displayed on the terminal, guide the operator in conducting the test and preclude damage if a leak exists in the system. The AP/SAP regulator executes a built-in test upon application of power and the results are stored in non-volatile memory, which can be viewed by maintenance personnel. Non-volatile memory is used to store transducer calibration curves, built-in-test results and limits, and aircraft parameters. There are also built-in procedures for normal maintenance and calibration.

The AP/SAP was designed with built-in safety features that protect against negative impact pressure, rapid depressurization at power loss and overpressure, as well as sensing errors due to leaks in the lines under test. Because of the ability to be used by a single operator, the unit improves productivity while reducing damage to air data sensors.

DIRECT NUMERICAL CONTROL

MCAIR's Direct Numerical Control (DNC) system currently sends NC motion data to, and retrieves feedback data electronically from, over 170 devices, ranging from two axes reciprocating knife cutters for composite cutting to three spindle, five axis gantry profilers for titanium bulkheads. The system is operational 24 hours a day, seven days a week.

All part programs are archived on an IBM 3090 host computer. The DNC supervisor is a dual configured Concurrent Computer Corporation 3260 system. The dual configuration gives MCAIR a complete back-up system. Advanced Micro Z8000 microcomputers serve as the interface from the supervisor computer to the machine control units at the machine tool and have bubble memory capability. The bubble memory allows downloading and storage of NC program data well ahead of actual run time, thereby buffering the device's production from system or communication problems.

MCAIR's bi-directional DNC system links allow a full complement of feedback information to be sent from the device to the DNC supervisory computer. Information accounting for device usage downtime, maintenance, and part set-up is accumulated, tabulated, summarized, and stored in a database easily accessible to production and maintenance management, methods engineers, and systems engineers. This feedback data is very useful in evaluating improvements, setting program target times, troubleshooting, and production planning. The data collection feature also permits real-time monitoring of device activity.

The DNC system currently handles 180,000 part program requests per year. Future enhancement plans include the installation of next generation controllers to perform post-processing at the machine tools, developing new machine tool interfaces using industry standards, and integrating DNC into the process center environment.

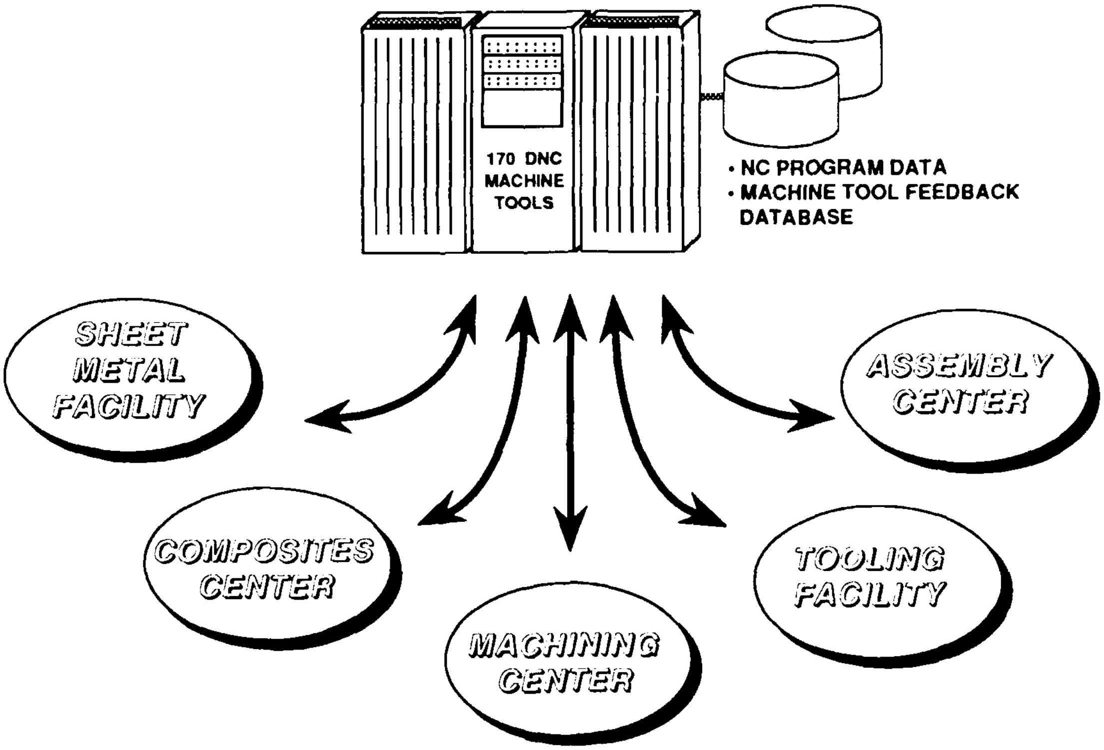

Figure 3.3-5: MCAIR's DNC System Sends NC Motion Data to, and Collects Feedback from, over 170 Machines

DIRECT NUMERICAL CONTROL CUTTER VERIFICATION

MCAIR has implemented a DNC cutter verification system on all profilers with Actrion III controllers to reduce material scrap and rework due to incorrect cutter usage. The system consists of procedural checks made to the machine by the machine tool operator. These checks are compared to tool identification data encoded in the NC part program. If the wrong tool identification code is received by the machine control unit, the part program will not be downloaded and the operator will not be able to run the part. The system ensures that cutters are changed when required. It reduces tool changing errors by at least 80%.

GENERIC CUTTER DIAMETER COMPENSATION SYSTEM

MCAIR is developing the Generic Cutter Diameter Compensation System to provide an effective method to make use of used end mills. The MCAIR machining center is a large consumer of standard end mills. The system dynamically compensates NC program tool path information based on available end mill reground diameter. NC program data is created, but is based on a general cutter diameter. When this program is called down to the shop, a tool crib person measures the actual cutter to determine its actual diameter. The cutter diameter compensation routine will then regenerate the NC program path based on the actual diameter of the cutters assigned to that job.

The cutter diameter compensation system will be generic in nature in that it will not be restricted to a particular type of machine control unit. The system is currently developed for two axis equipment and is targeted for a phased implementation on production machines beginning in July 1989. The system will be capable of producing a 3D offset path, suitable for five axis milling.

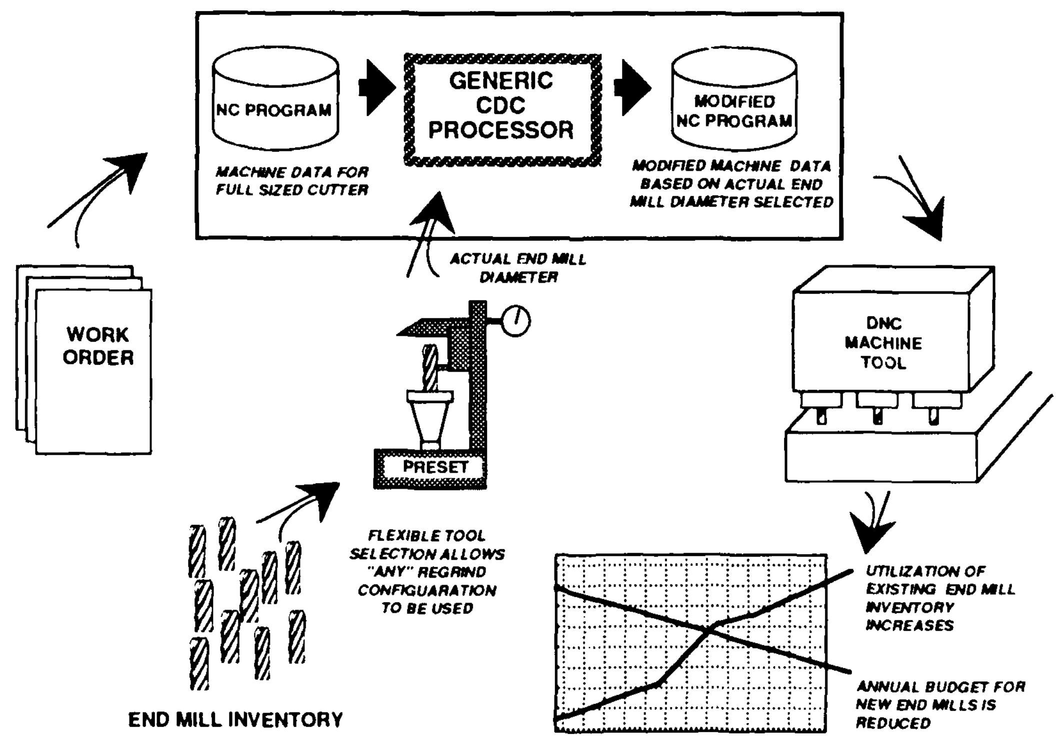

Figure 3.3-6: The Generic CDC System Dynamically Compensates the NC Motion Data Based on the End Mill Diameter

PROGRAMMING OF COORDINATE MEASURING MACHINES

Computer Aided Quality Assurance (CAQA) is a software tool used to produce inspection aids such as inspection documents or coordinate measuring machine (CMM) programs. It is integrated into the company's CAD/CAM environment.

One of the most important applications of CAQA is for off-line programming of CMM's. Using CAQA, a programmer can quickly and easily generate a CMM program to dimensionally inspect a selected part. The programmer generates inspection points using a light pen or may select standardized point patterns, which place inspection points upon a surface in a uniform pattern depending on the size and complexity of the surface being probed. CMM programs are automatically generated in the Automatic Programmed Tool (APT) language. The program is then scheduled using the Remote APT Processing via Interactive Device (RAPID) software which allows the program to be stored in the Numerical Control Information Management System (NCIMS) until requested by the operator at the CMM for inspection. The source program may be edited at the graphics terminal or any remote via RAPID to make required changes or corrections.

DECISION TABLE PROCESSOR

The MCAIR Decision Table Processor (DTP) is a set of system development tools designed for expert systems development in a production environment. The MCAIR DTP runs on existing IBM, DEC, and Concurrent computer platforms using terminals available throughout the MCAIR plant. The system is designed to give existing production facilities an expert systems capability and to provide for new expert systems development, by either the production end-user or the system developer without requiring formal AI training. The DTP provides the developer with a user interface, a decision expression language, a knowledge base, and an inference engine.

The DTP was used to build MCAIR's generative process planning system, the F/A-18 boresight alignment system, cutter deflection system, composite tool selection system, and others.

EXPERT BUSHING SYSTEM

The Expert Bushing System assists in the specification and machining of repair and special bushings. The system reduces labor costs and production times. Savings are projected to exceed $100K annually. Before the implementation of the system, excessive time was spent interpreting bushing specifications and generating working sketches. A high scrap rate resulted from misreading bushing specifications and from mistakes made when creating working sketches.

The system is made up of three modules: the design assistant, the bushing specification decoder, and the NC program generator. The design assistant aids the designer by prompting for design data and accessing a database for interference fits and tolerances. This reduces time spent searching for this information in manuals.

The bushing specification decoder translates the bushing specification, a character string, and produces a design drawing as well as textual data. This includes part dimensions, appropriate cautions, and material notes.

The NC program generator produces a machine code program from the bushing decoder design information. Template programs for each type of bushing are stored, and a new program is generated by merging bushing dimensions from the decoder into a copy of the template program.

The first phase of this project, the development of the bushing specification decoder for the LE101 bushing type, has been completed and is now in pilot production. The second phase, which involves the automatic generation of machine code programs, is nearly complete. Full scale development will be done concurrently with the development of the design assistant. Future plans include applying this system to other production parts.

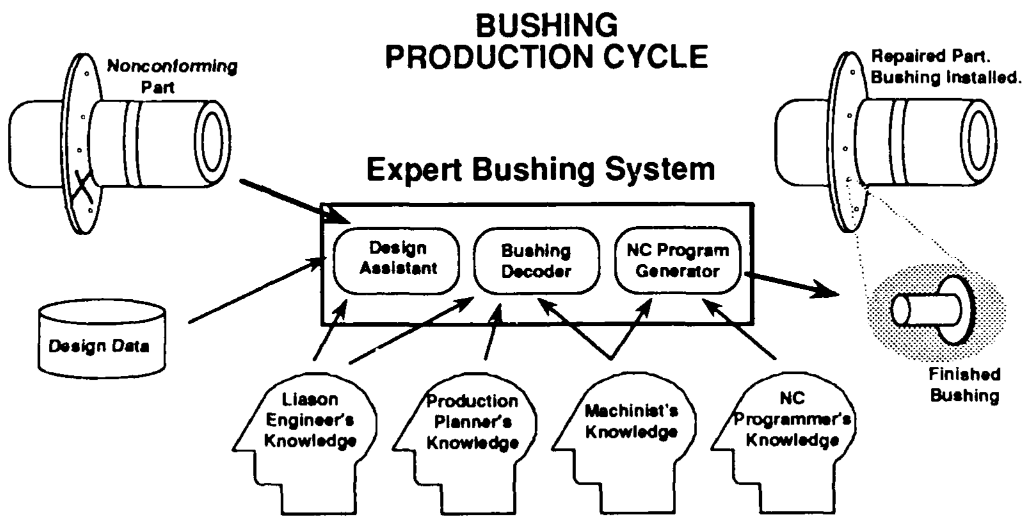

Figure 3.3-7: The Expert Bushing System Aids in the Production of Repair and Special Bushings

MAKE OR BUY EXPERT TOOL

The make or buy expert tool provides a consistent means of determining whether a part should be manufactured in-house or subcontracted to an outside vendor. This is done by identifying constraints such as part cost, material, geometry, special processing requirements, quantities, current and future machine shop workload, vendor resources, and the required delivery date. The system analyzes new parts based on these parameters, produces a make or buy recommendation, and records the recommendation along with the evaluation data used. This historical database provides traceability of part recommendations, factors considered, and the actual implementation data.

The system is undergoing pilot production testing. Future enhancements and modifications to the pilot production module include extensions to other types of machines, tooling feasibility analysis, and links to a parts attribute file.

F/A-18 BORESIGHT ALIGNMENT

The F/A-18 boresight alignment expert system is a PC based program which incorporates alignment technician expert knowledge and the MCAIR Decision Table Processor (DTP) technology. It was created to assist technicians with instructions for calibrating the F/A-18 Triaxial Detector Unit (TDU). The TDU is a key component of the F/A-18 triaxial alignment set, a precision optical device used to provide boresight alignment of the F/A-18 weapon replaceable assemblies.

Alignment of the TDU is complex and requires a high skill level. The expert system provides the technician with a consistent approach to the alignment process and provides clear instructions for this process. It eliminates the mathematical calculations that were previously done by the technician and has greatly reduced alignment errors. The expert alignment system has been used at MCAIR for six years. It has reduced the number of iterative adjustments required and cut alignment time by 50%.

WIRE HARNESS INTELLIGENT TASK SCHEDULER

The wire harness intelligent task scheduler incorporates expert system technology and object-oriented programming techniques. The system generates schedules and work assignments by simulating shop operations for up to ten shifts. The intelligent task scheduler provides the shop foreman with a tool to schedule the production of many different types of wire bundles and other electrical assemblies. It balances out conflicting scheduling requirements and reduces the amount of work in process.

Unlike many shops, the availability of machinery is not the factor limiting production. Skilled workers are considered the resources to be allocated. Multiple workers may be assigned to a single type of station.

The wire shop scheduling system examines scheduling constraints, worker and skills availability, and work order need dates to prioritize all available work orders. The system also determines a specific routing for each work order. An explanation capability is incorporated which describes the reasoning basis for each particular routing path and the assignment of work order priorities. The user has the ability to override the assigned priority.

The scheduling system was originally developed using the KEE software package from Intellicorp, but has been converted to the "C" programming language. The system is currently used in the production area to create schedules at the beginning of each shift based on the simulation.

PORTABLE MACHINE DIAGNOSIS SYSTEM

The Portable Machine Diagnosis System (PMDS) is an expert system designed to provide machine shop maintenance electricians with a formal methodology for diagnosing problems relating to machining equipment. PMDS is implemented on a portable personal computer that can be taken to the site of the malfunctioning machine tool. It has been developed to diagnose the General Electric inverter drive section on the Cincinnati Milacron gantry profiler machines. The long term goal for PMDS is to extend its capability to diagnose five types of machine tools whose downtime has a critical impact on production.

PMDS leads maintenance electricians through a series of tests in order to recommend repair actions. The diagnosis is controlled by expert system software. After tests and repairs are performed, PMDS recommends machine check-out procedures to ensure that the repaired machine is fully operational.

The benefits of PMDS include a reduction in machining equipment downtime; the capture, retention, and dissemination of knowledge from experienced MDC maintenance electricians and MDC training instructors; and a reduction in the costs associated with subcontracting work that can't be performed in-house due to the lengthy repair time.

PAPERLESS ELECTRICAL ASSEMBLY PLANNING SYSTEM

MCAIR is in the process of implementing the Paperless Electrical Assembly Planning System for use in the manufacture of electrical wire harnesses. The planning system consists of a computer network which provides fabrication information to shop and support group users.

The system will place a terminal at each workstation. The operator will select a particular assembly and will then be able to retrieve information relative to each branch and connector in that assembly. The operator can then obtain data specific to each wire and the location of that wire in the connector.

This system will provide current information to all shop and support users as soon as the data is updated or changed. The system incorporates extensive data checking and automatically reports problems to the supporting department responsible for the error so that updates can be made quickly. Support labor is reduced through the elimination of maintaining paper worksheets. Direct labor is reduced by enabling the operator to concentrate on wire assembly rather than searching for assembly data. MCAIR estimates that as many as 100 workstations will be added for various processes over the next two years.

EMILIE PROGRAMMING SYSTEM

Emilie is a high level programming language developed to operate within MDC's CADD system. It was designed to provide a means for extracting and manipulating CADD part data for various applications. The initial use for Emilie was off-line machine programming. For this application, it was utilized to program the windshield and canopy drilling system, the AV-8B wing drilling system, and the master model scriber. Machine programs are produced by extracting the necessary part geometry from the CADD database and by using a specially written module to convert the data into the required format for the designated machine tool.

In April 1987, Emilie was released as a graphics application programming language for the CADD system. Emilie features a Pascal-like syntax and operates in an IBM/CADD environment. Programs written in Emilie are used for interrogating, creating, or modifying a CADD model. Emilie provides the capability for creating CADD graphics applications by persons not possessing detailed knowledge of the CADD system. The system will also allow the execution of programs written in other languages as Emilie functions.

In mid-1988, tool design engineers at MCAIR requested assistance in preparing data for NC inspection sheets. A considerable number of tools for the C-17 program were in the design process. Each required verification of hole locations. Due to the amount of inspection sheets required, the traditional method of manual inspection sheet preparation would have been very time consuming. An Emilie program was written. The program was developed within one week and has substantially reduced the time required to prepare the inspection sheets.

SHEET METAL CAM SYSTEM

The MCAIR sheet metal CAM systems integrate engineering CAD systems with DNC machining systems for sheet metal aircraft parts fabrication.

Capabilities and features of the system include:

* CAD system interfaces such as CADD and Unigraphics.
* Graphic nesting.
* Automated NC program generation.
* Detail parts graphic aids (CRT or hard copy).
* Nest and machine set-up graphic aids.
* Machining optimization.
* Batch process nesting.
* Quality verification.

Machining processes included in the system are drilling, routing, milling, laser cutting, water-jet cutting, punching, blanking, scribing, and wire electrical discharge equipment.

The sheet metal CAM system has been implemented into different manufacturing environments at MCAIR, Douglas Aircraft Company, and at MDC facilities in Tulsa and Canada.

COMPOSITE CAM SYSTEMS

Composite CAM Systems (CCS) at MCAIR is a set of integrated computer programs that facilitate retrieval, processing, generating, and scheduling of composites manufacturing data from engineering defined digital data. CCS software is currently used at both MCAIR and McDonnell Douglas Helicopter Company. Major systems of the CCS include:

* Gerber Cutter Labeling System - Retrieves flat pattern composite parts from the CADD database. Creates nests and machine programs for the Gerber. Automatically generates shop floor graphic files.

* Nesting System - Consists of three different types of nesting, each in a separate line. Static Nesting (single part nesting)/Dynamic Nesting (concatenates static nests, and reduces machine set-up time)/Automatic Multiple Part Nesting (Enables grouping of static nests into multiple part nests).

* Graphic Display System - Automatically creates graphic files for each nest. Provides shop floor graphic aids for the nest. Eliminates manual preparation, filing, and tracking of paper instructions.

INTEGRATED COMPOSITES CENTER

The Integrated Composites Center (ICC) program is an integral part of MCAIR's factory-of-the-future strategy and forms the foundation on which it will be built. The base program is being sponsored by the Air Force's Manufacturing Technology Directorate. The objective of the ICC program is the full integration of composites shop floor operations with CIM, planning, scheduling, and control. This is to be accomplished through effective information sharing and efficient management information flow. The four-phased, four and a half year program is currently entering its fourth year of development during which incremental implementation and demonstration of all the ICC technologies will occur.

There are three major elements of the ICC:

* Shop Floor Processes - Many of the shop floor processes are being automated and integrated through computer systems.

* Planning and Control Systems - The logical systems necessary to effectively plan, control, and manage the operations.

* Information Management System - The computer hardware, the system level software, and the communications network.

Three areas involving recent implementation or near term implementation include the Integrated Scheduling System, the Gerber Cell, and the Archival Storage and Retrieval System, which are described below.

INTEGRATED COMPOSITES CENTER GERBER CUTTER

MCAIR's Gerber cutting area is unique because of the information management system associated with the cutter. The management system totally eliminates paper work orders following the material through the cutting and kitting process. Parts are released through an electronic information system in a sequence that is required to meet the aircraft delivery schedule. The Gerber information system sets the sequence and quantity of the plies to be cut so that the time/temperature profile of the composite plies will not be exceeded before they are used.

Information can be called up on a CRT screen that has all of the inspection checks and all of the cutting information that the paper work orders currently have. An operator is required to check off items from a menu and enter his badge number as verification that the task is complete. The information system reduces the number of cutting operations from nine to five and the inspection operations from three to one. The system eliminates paper handling mistakes; improves the quality of the parts by eliminating their out time; provides reliable verification of material and processes; and increases throughput by eliminating paper handling. The system also keeps unqualified personnel from performing tasks.

INTEGRATED SCHEDULING SYSTEM

As part of MCAIR's ICC program, a factory level Integrated Scheduling System (ISS) is being developed that will provide a single source of information for management and planning activities. It will also serve as a basis for the coordinated scheduling of tools, materials, parts, and assemblies.

The ISS considers contracted delivery dates in the automated generation of milestone dates for ramp operations and final and major assembly operations. It also tracks production status to these milestones. Schedules are presented to users in both text and graphic forms and provide near-instant availability of updates and modifications. The ISS is scheduled to be implemented as part of the ICC during the second quarter of 1989.

INTEGRATED COMPOSITES CENTER ARCHIVAL STORAGE

With the advent of all electronic plans and work orders within the ICC, a non-paper mechanism for archiving historical information had to be established. MCAIR selected an Optical Disk Storage and Retrieval (OSAR) system that utilizes write-once-read-many technology.

The OSAR system, supplied by FileNet, can file the equivalent of 1,000 paper filing cabinets in a 6 x 12 foot disc storage cabinet. OSAR reduces paper handling, speeds the archiving process, and reduces loss. In addition, OSAR saves time. Current searchs take minutes instead of days.

COMPUTER AIDED CURING OF COMPOSITES

The Computer Aided Curing of Composites program is sponsored by the Air Force Wright Aeronautical Laboratories, and has the potential to reduce the cost of manufacturing by optimizing the part batches, reducing the cure cycle time, improving the scheduling, making more reproducible parts, and improving quality. The process simulation model allows for cure cycles to be developed and checked without risking parts or using autoclave time. The model can also be used to develop more efficient tools, which will produce better parts at lower cost.

The computer programs have been used to develop a cure cycle for AV-8B spars. This process has been reduced from 14 to nine hours with no loss of material properties. Limited testing has shown that savings of 26% are possible in bismaleimide processing. The real improvement in processing will come when this system is utilized to provide the cure schedule for all cured parts. Real-time feedback and control of the autoclave through this program will provide a truly unique process.

TECHNOLOGY TRANSFER

Internal technology transfer addresses means of transferring knowledge and lessons learned throughout MDC to eliminate redundant efforts and enhance the benefits of sharing ideas and resources. This is done primarily through two steering groups, one for Computer Aided Engineering (CAE) and one for CAM, each having members from all divisions of the corporation. These groups serve as catalysts for the effective use of computer resources in performing engineering and manufacturing functions at MDC.

Examples of internal technology transfer include the use of the MCAIR CAD systems throughout MDC, the use of Electronic Development Fixture and lessons learned on the AV-8B for the Douglas Aircraft Company T-45, and the implementation of a shared Cray computer facility. Additionally, MCAIR participates in corporate committees such as the MDC Bar Code Committee and the MDC AI Committee.

External technology transfer addresses exchange of CAD/CAM technology throughout domestic industry and some foreign industry. MCAIR is very active in external technology transfer. MCAIR's motivation for participation in external technology transfers are to share knowledge, technology, and trends by participating in organizations and company-to-company exchanges. MCAIR is particularly interested in influencing standards, especially in the area of product data exchange. This influence on standards is especially important for maintaining a competitive edge in the changing business environment which requires teaming partners and the necessity of addressing the complete product life cycle in a digital format.

Examples of external technology transfer include MCAIR's participation in CAM-International (CAMI), Manufacturing Automation Protocol/Technical and Office Protocol (MAP/TOP) development, standards organizations, trade shows, and academic efforts.

3.4 FACILITIES

ADVANCED TOOLING FACILITY

The Advanced Tooling Facility at MCAIR is a manufacturing facility specifically developed for the fabrication of tooling to be used in aircraft production. The 360,000 square feet climate controlled facility was occupied in 1986 and secured in 1988. The facility includes a 40,000 square feet assembly area with a full complement of modern equipment. This equipment includes computer numerically controlled (CNC) and DNC mills and lathes, two large five axis machining centers and wire electronic discharge machines (EDM). The newest and most productive manufacturing methods and management philosophies employed by MCAIR are used in the Advanced Tooling Facility.

The facility is organized into different manufacturing cells. Currently there are ten active cells and eight other cells in various stages of development. Simulation techniques are being used to aid in the design and implementation of the tool grinding cells. A simulation package is used to evaluate part flow, track inventory levels, and identify possible bottlenecks in the system.

Inventory levels are controlled with a computer based just-in-time (JIT) material procurement system supplied by Jorgensen Steel Company. The system provides rapid turnaround and reduces lead times on procurements. Inventory levels are kept to a minimum and inventory costs are reduced.

Many new and productive manufacturing practices are utilized in this new facility. Some examples are:

* Increased use of theodolites in production and inspection of large assemblies.

* Photogrammetry and digital inspection machines are used to inspect assemblies.
* "Renfoam" (a wood-like substance made of plastic) can be glued and machined to produce master models.
* Computer verification will be implemented to reduce or eliminate the practice of cutting wax blanks to verify NC programs.
* Paper tool orders are eliminated by the Automated Tooling Order (ATO) system.

MASTER MODEL SCRIBING AND DRILL CELL

MCAIR has developed and installed a robotic cell to scribe lines and drill holes in master models and other similar parts. This process was very labor intensive prior to automating the process. Consistent quality of lines and holes was also a problem. The cell consists of a five axis Cybotech gantry robot and controller and an IBM PC. Data is provided to the PC from the CADD mold line database residing in the IBM mainframe.

A significant decrease in tool build time is achieved by off-line programming of the robot concurrently with the construction of the master model. Additional tool build time is saved by quick part set-up in the cell by use of a tactile sensing system, and by rapid robotic line scribing and hole drilling. The high quality scribed lines and holes result from the use of an ultrasonic scribing end effector and a controlled feed rate drill end effector.

CRYOGENIC TOOL CLEANING CENTER

The cryogenic tool cleaning center is a unique state-of-the-art method for cleaning tools. It is a semi-automated process using machines to convert CO_2 from a liquid to a solid. The 1/8" diameter by 1/4" long pellets are conveyed through a blast nozzle at 130 psi onto the surface of the tool. Cryogenic temperatures and impingement of the pellets causes the cured resins to release from the surface of the tool. The CO_2 pellets sublime, which leaves only resin to clean up.

The Cryocleaner can be used to clean all types of tools, fabrication aids, and part details. It can remove release agents, resin, adhesive, tape, and other organic materials. It eliminates damage to metal tools and has potential for cleaning composite tools. The cryogenic system is faster than abrasive or solvent systems.

The cryogenic technique was adopted after attempts to use other systems such as walnut shells and plastic pellets proved to be ineffective. MCAIR is using second generation equipment, which uses improved materials and has better control of the blast pressure and shape. The equipment is manufactured by Alpheus Cleaning Technologies.

MCAIR has shown a reduction in labor of more than 20% with an improved work flow and no tool damage while using the cryogenic cleaning system.

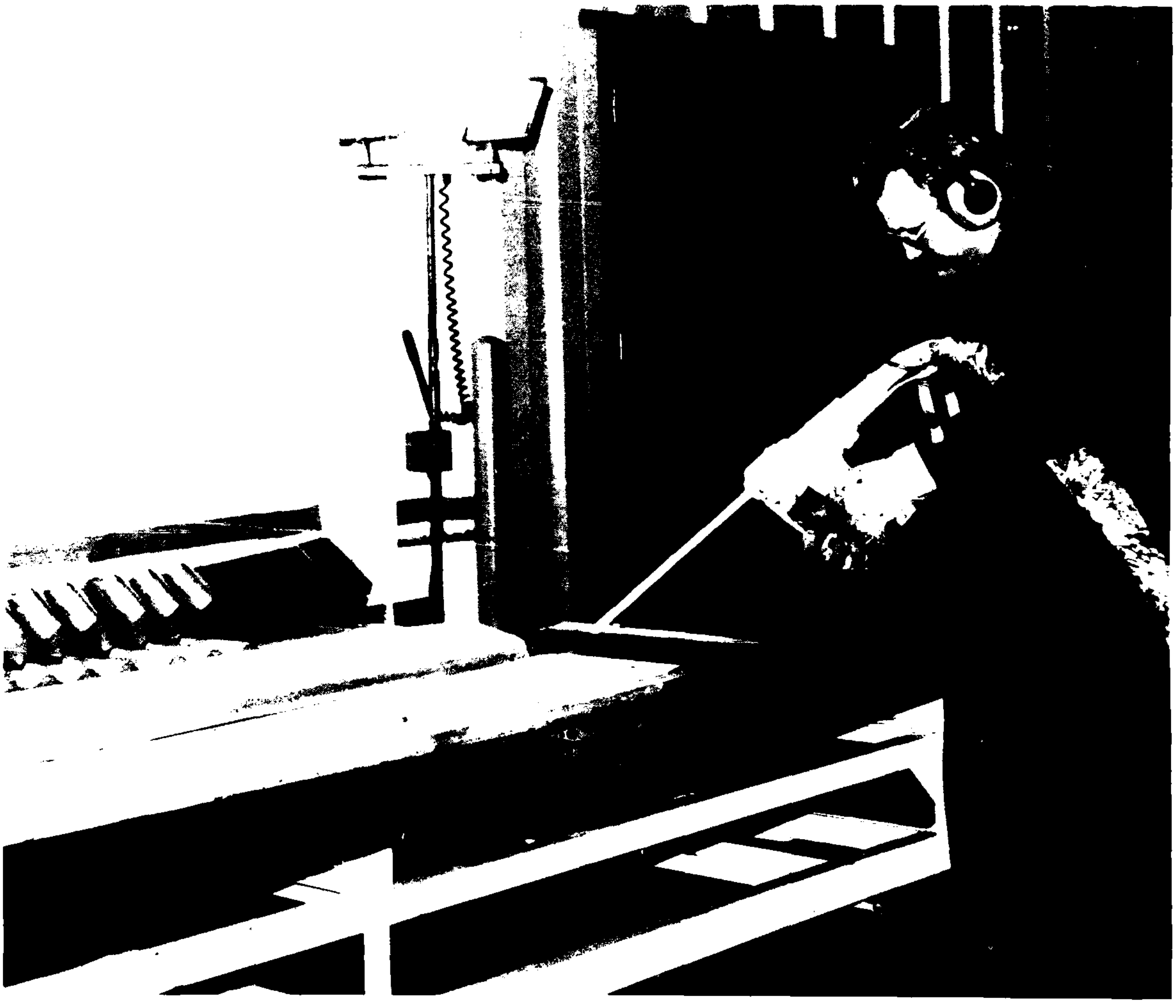

Figure 3.4-1: The Cryogenic Cleaner can Remove Release Agents, Resin, Adhesive, Tape, and Other Organic Materials Without Damaging Metal Tools

PHOTOGRAMMETRY AND THEODOLITES

MCAIR has been successfully using photogrammetry and theodolites for periodic reinspection of aircraft assembly tools for over six years. Both methods are portable and accurate (up to 0.001"). Photogrammetric measurements are used on objects that require more than 60 reference points. Since film is used, this system is not real-time, but imaging can be accomplished quickly so there is relatively short down-time for items measured.

MCAIR's photogrammetry equipment is supplied by Geodetic Services, Inc. A Compaq 386 PC is used for analysis of the digitized image data. Theodolites are used for applications requiring less than 60 reference points. The equipment is digital and can be connected to a computer for real-time measurement and analyses.

Both methods have been applied in a variety of innovative ways at MCAIR. Photogrammetry has been used to measure objects as small as a six inch panel and as large as a whole F-15 airplane. It has also been used for time-motion and shape definition studies as well as for reverse engineering. High speed photogrammetric techniques were used very effectively to analyze bird strike impact effects on canopy sections. Theodolites have been used extensively in troubleshooting problems which require high accuracy measurements.

MCAIR is planning new applications for these measurement methods including using theodolites to manufacture tools without creating masters.

COMPOSITE DRILL AND ROUT ROBOTIC CELL

The Composite Drill and Rout Robotic Cell was implemented into production in September 1987 to perform template drilling and routing operations. The cell uses a Cincinnati Milacron 776 electric drive robot controlled by a DEC 11/73 computer for program data storage and sensor feedback calculations.

The robot is teach-programmed using a five axis proportional tactile position sensor. Initially, the operator "rough" teaches the robot to within 1/8" and is not concerned with end-effector normality to the part surface. The tactile position end-effector is inserted and the robot goes back through the "rough" part program to determine accurate hole data. Each time the part program is executed in production, the robot uses the tactile position sensor in three holes to determine the fixture location and adjusts the program accordingly. An automatic reteach program is also easily executed in the event of a small change in the template definition or robot positioning accuracy. This takes approximately as long as it would to run a normal drilling sequence. With this system, part programming is cut in half versus traditional teach methods.

The coolant used for drilling and routing has kept virtually all composite fibers and dust out of the air. The robot has a multiclutch torque sensor, which monitors the tool tip and shuts the robot down in the event of excessive forces. The cell has significantly increased part quality and has virtually eliminated hand finishing of routed edges.

AUTOMATED COMPOSITE TRIMMING

In an effort to reduce the labor intensive process of trimming composite parts, MCAIR is in the process of installing an abrasive water jet trimming system which was purchased from ASI Robotics, Jeffersonville, Indiana. The unit consists of two 9 x 11 foot beds, and cuts at a rate of 2.5 - 4.0 inches per minute using a pressure of 45,000 psi. MCAIR will use the water jet to trim composite wing skins.

PLY HANDLING SYSTEM

The ply handling system is the heart of the composite fabrication process at MCAIR, providing the capability of cutting, sorting, packaging, and distributing ply sets to the various cells for subsequent lay-up operations. The system consists of four workstations:

* Automated Ply Cutting and Labeling. This is accomplished through the use of two DNC Gerber cutting machines. Incorporated into each system is an automated material dispensing and labeling subsystem that dispenses preimpregnated broadgoods on the 44 foot cutting bed and applies optically readable labels. Each dual bed system utilizes a reciprocating knife to cut prepreg broadgoods up to four plies deep. The present daily output from this operation is 1,850 lbs. or 5,000 plies.

* Ply Sorting Machine. Once the plies are cut, they are transferred to a fully automated ply sorting machine. The machine consists of four traditional NC axes and five additional canned axes. Here, the machine takes the unsorted plies, optically reads the label, automatically inputs them into the buffer storage unit, then sorts the plies in numerical order.

* Ply Packaging Machine. The handling trays containing the sorted ply packs are automatically packaged by applying a polyfilm around the tray followed by a heat sealing operation.

* Ply Distribution Center. This center, which measures 130' long x 15' wide x 25' high, provides short term storage for over 2,500 ply sets. The center controls the release of ply sets to layup cell customers, tracks material shelf life, and accounts for ply set locations.

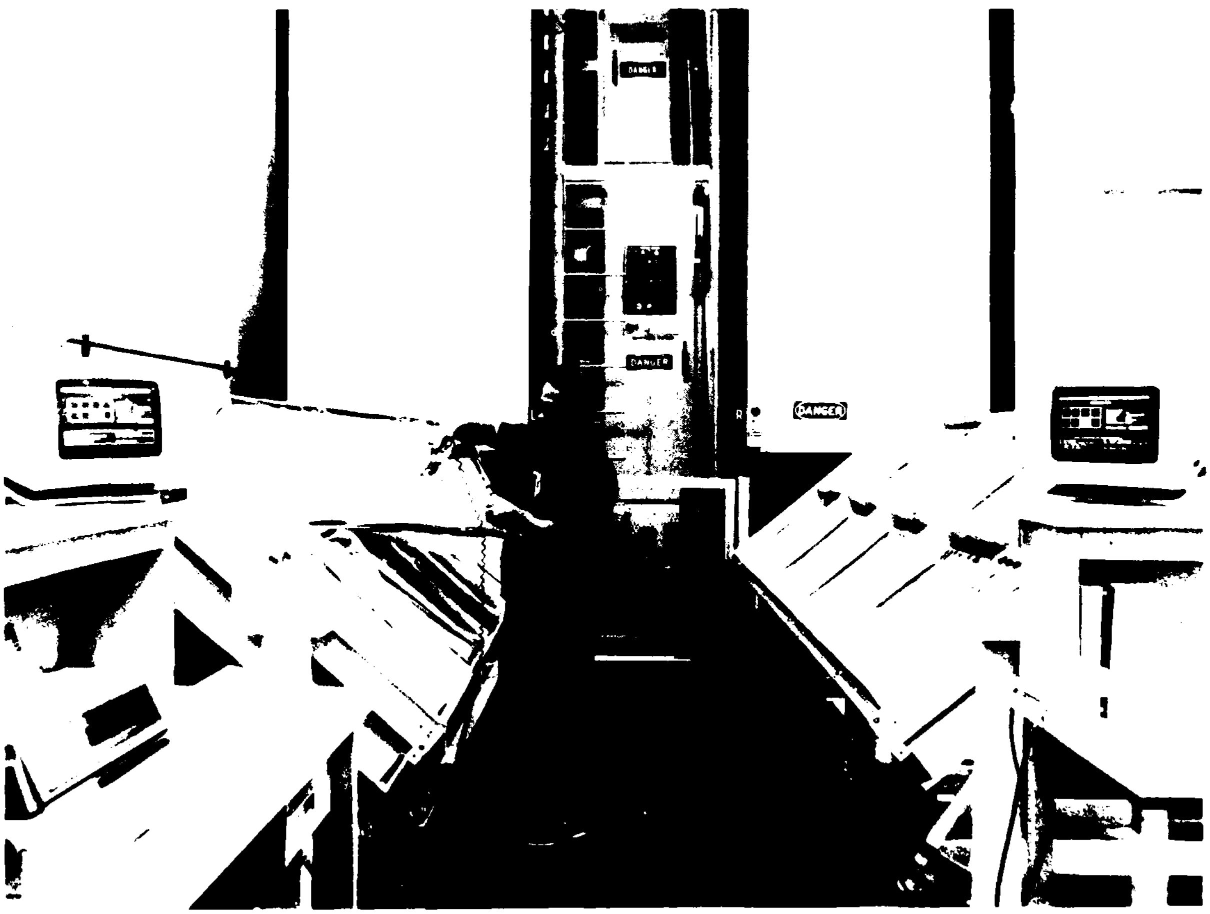

Figure 3.4-2: The Ply Distribution Center Provides Short Term Storage and Tracking of over 2,500 Ply Sets

ROBOTIC ROUTING CELL FOR SHEET METAL

A robotic routing cell for trimming contoured aluminum panels is being used in the sheet metal fabrication facility and has resulted in cost reductions as well as improvements in quality and productivity.

The cell has four workstations, which can be rearranged to take larger parts. The four cells allow for simultaneous robotic trimming and manual set-up of the next part. The cells use traditional manual trim fixtures. The robot end-effectors are changed automatically.

Complete cell operation is accomplished by router operators who have been specially trained to program the robot.

SUPERPLASTIC FORMING

MCAIR is currently installing a 2,400 ton superplastic forming (SPF) press for forming part sizes up to 4 feet by 8 feet and is planning to acquire a SPF triple action press for forming more complicated part shapes.

Conventionally fabricated aluminum assemblies contain numerous detail parts and fasteners. Parts with complex geometries are difficult to form accurately. Fabrication and assembly costs are high. In addition, honeycomb reinforced structures involve high fabrication costs, are difficult to repair, and experience high life cycle costs. The use of SPF would eliminate most of these problems.

SPF of titanium at MCAIR has resulted in cost savings of 20% to 50% and weight reductions of 10% to 20% when compared to conventional manufacturing methods. Approximately 150 parts are manufactured by the SPF single sheet process. In addition, 13 two sheet and four sheet structures are produced by the SPF/diffusion bonding (DB) process. The F-15E Builtup Low Cost Advanced Titanium Structures (BLATS) Program provides an example of the advantages of the SPF and SPF/DB processes. In that program, the number of components was reduced from 772 to 46 and 10,000 fasteners were eliminated. Life cycle costs are also projected to decrease.

MCAIR is increasing its investment in SPF and SPF/DB equipment in anticipation of increased applications in future aircraft.

HIGH PRESSURE FORMING PRESS FACILITY

High pressure forming will improve the quality and producibility of metal parts. The press facility is currently being installed and is planned to be operational by June 1989. The facility consists of a 25,000 ton press with an eight pallet, fully automated handling system. The press will provide forming pressures up to 30,000 psi, which enables optimum forming operations on rubber formed parts. High pressure forming eliminates hand line-up on the majority of parts and enables most parts to be formed in one hit versus the two and three hit forming operations required with lower pressures. This results in up to 70% reduction in hand line-up time and up to 66% reduction in part cycle time. MCAIR projects that 750,000 parts will be formed annually in this facility.

Figure 3.4-3: The use of SPF in a High Pressure Press Allows the Formation of Parts that would Require Numerous Details and Fasteners if Conventionally Fabricated

LASER SCRIBING OF CHEM-MILL MASKS

Automated laser scribing of chem-mill masks was implemented to replace a manual scribing process.

The automated laser process was applied to flat parts which comprise approximately 20% of MCAIR's chem-mill workload. A three axis laser scribing machine was obtained commercially for $250,000. Software development cost an additional $100,000. The automated laser process can be applied to curved parts at a cost of approximately $160,000 per controlled axis.

Automation of the process provided four immediate advantages:

* Lower scribing costs.
* Improved scribe line quality.
* Elimination of hard tooling.
* Reduced number of tools in storage and repair.

WATER BASED CHEM-MILL MASK

The water based chem-mill mask eliminates solvent (perchloroethylene) emissions associated with traditional solvent based masks. Overall performance of the water based mask is equal to the solvent based mask. Savings are realized through a single coating cycle since no part reversal is required to achieve an even coating. There are also no solvents to contain or dispose of. Some disadvantages of the water based system are a lower tensile strength and a more difficult process to repair scribe lines. Mixing problems and long term viscosity increases have been overcome by MCAIR and the material vendor.

Over 650 production parts have been processed using the water based mask. The parts were coated and then processed per standard chem-mill practice. The water based system is made by Desoto Chemical Company. Other similar products are made by 3M Company and A C Products Company.

AUTOMATED SEALER PLUG INSERTION CELL

MCAIR is currently moving toward cellular manufacturing concepts and automation where reasonable implementation costs and maximum savings can be achieved. The automated sealer plug insertion cell is an example of this practice. Installed in the fall of 1984, the cell paid for itself in 1.3 years.

The cell consists of a Nova Aries cartesian robot and a three axis controller. It has a +/- 0.010 inch positioning accuracy and a +/- 0.001 inch repeatability. The end-effector and feeder bowl system were procured from Weber-Systems, Incorporated. A DEC PDP11/44 computer system retrieves the necessary data from the engineering database and automatically programs the robot off-line.

The cell was installed to decrease labor cost, improve quality, and eliminate the monotonous task of manually inserting sealer plugs into the spare cavities of electrical connectors. MCAIR's annual usage of these plugs is 1.6 million, of which 95% are about 3/64" in diameter and 7/16" long. The cell has the capability to install 3,000 plugs per hour with zero defects. It has significantly reduced the labor cost for this tedious job.

AUTOMATED WING DRILLING SYSTEM

MCAIR has implemented an automated drilling system on the AV-8B production line, which drills over 6,000 fastener holes on the upper and lower surfaces of the AV-8B wing. The wing measures 28.3 feet in length with a 38" dihedral. The wing torque box is primarily carbon-epoxy with some aluminum and titanium. Both upper and lower wing skins are one piece carbon-epoxy structures. MCAIR and the Navy shared initial technology development funding.

The wing drilling cell is enclosed in a pit approximately 105 feet in length, 16 feet in height (eight feet of which is below shop floor level), and 23 feet in width. Two DNC gantry machine tools built by Ingersoll Milling Machine Company each support a vertical drilling column. The gantries travel the length of the pit on rails mounted on the top of each side wall. The drilling heads have six axes of positioning and a +/- .001 inch repeatability. Each machine is controlled by a General Electric 2000 controller which interfaces with the drill cell supervisory computer.

After a wing torque box is loaded into the cell, an optical scan using a camera mounted in the drill spindle locates the centerline of pre-drilled pilot holes to +/- .003 inch. The hole locations are compared to theoretical pilot hole data stored in a CADD model of the wing. The CADD model is then adjusted to account for normal assembly tolerances. The bottom wing skin is attached to the torque box using automatically inserted slave bolts, which are stored in a bowl feeder located on top of the gantry and fed to the machine spindle through a tube. The wing skin and torque box are then automatically drilled. Upon completion of the drilling cycle, the lower wing skin is removed and the upper skin is attached and the sequence is repeated. The majority of the holes are drilled 3/16" and 1/4", with some being 5/16".

This system has brought together state-of-the-art servo drive and controller systems, vision technology, and correction techniques to automatically drill large, complex composite parts. The wing drilling cell has resulted in a reduction in direct labor and has reduced wing drilling time from ten days to approximately four. It has also resulted in improved part quality and reliability.

The automated drilling cell eliminates the use of portable drills and drilling blankets along with the associated handling, storage, and maintenance. The cell is currently dedicated to the AV-8B wing, but is versatile and capable of drilling and routing any aircraft assembly which fits into the system's 85' x 14' x 11' operating envelope. MCAIR is currently installing a similar system for use on advanced programs.

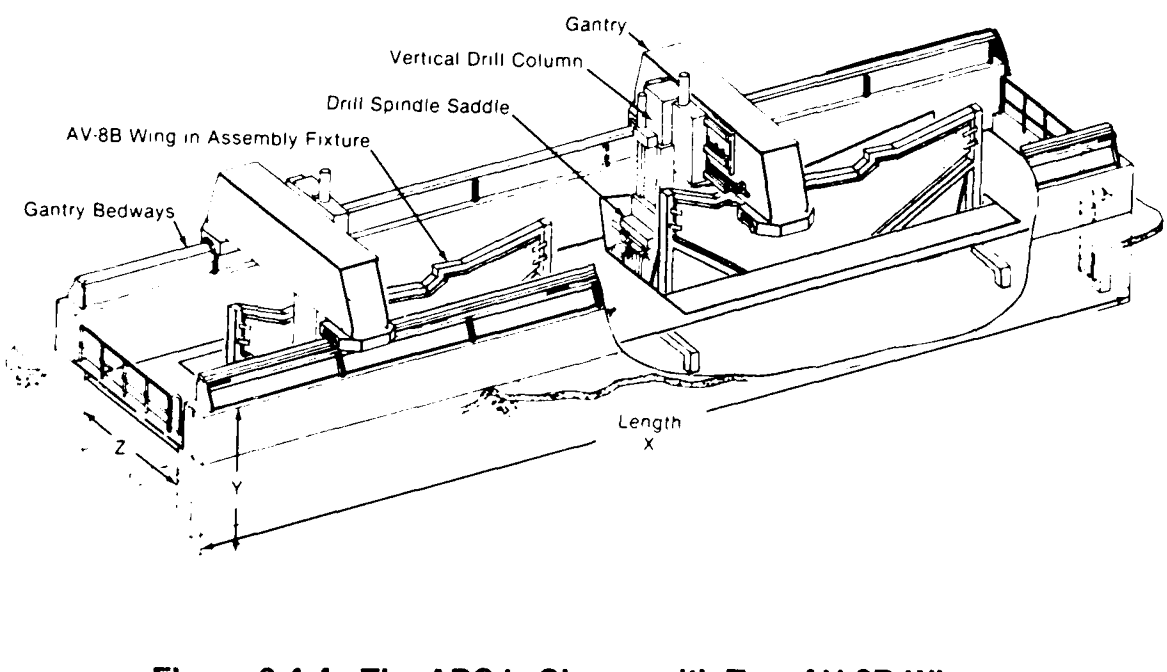

Figure 3.4-4: The ADS Is Shown with Two AV-8B Wings, but Is Capable of Drilling any Assembly that Fits in the Operating Envelope

ROBOTIC WINDSHIELD AND CANOPY DRILLING CELL

The robotic windshield and canopy drilling cell was implemented to drill the attachment holes for the F-15, F/A-18, and AV-8B acrylic windshields and canopies. The cell, which was installed in March 1986, uses a Cybotech G-80 hydraulic drive robot and is programmable off-line from the CADD system.

The robot manipulates up to four drill motors and provides a four to one cycle time reduction and a significant direct labor savings when compared to the manual process. The computer controlled Aero-Paramatic drill motors monitor the drilling process and automatically shut down if the process parameters exceed the pre-programmed limits. Process data is gathered, which provides a measure of the quality of the hole.

The cell uses a single camera vision system attached to the robot arm. After the robot has released the drill motor in the drill blanket, the image is used to accurately determine the position of a white dot on the drill motor. Depending on where the hole is being drilled, the drill motor may actually droop towards the shop floor. Determining exactly where the white dot on the drill motor is, and hence, where the drill motor is in space, allows the robot to pick up the drill motor without damage to it or the part being drilled.

Figure 3.4-5: The Windshield and Canopy Drilling Robot can Manipulate up to Four Drill Motors and Incorporates a Vision System for Drill Positioning

DIAMOND TIPPED DRILLS

Conventional carbide drills used to produce fastener holes in carbon-epoxy composites wear after producing an average of only 40 holes. Automated drilling operations require numerous tool changes because of the number of holes required. (Up to 6,000 holes are required in one wing alone.) Because of these problems, MCAIR and Precorp Corporation of Niles, Illinois, have co-developed a special polycrystalline diamond tipped drill. This drill is capable of producing 1,500 1/4" diameter holes and up to 2,500 3/16" diameter holes in carbon-epoxy composite material, before requiring a tool change. This has resulted in a 76% reduction in cost by reducing the number of tool changes, related tool holders, and back-up inventory of redundant tooling.

MCAIR developed the required geometry for the drill through tests conducted in its Advanced Manufacturing Fabrication Facility. Precorp Corporation has developed a proprietary process for the fabrication of these drills and has an exclusive license for its use. The figure below illustrates this process. A carbide blank is slotted and then inserted into a cube of polycrystalline and subjected to 2,700°F and 876,000 psi to impregnate the blank. The blank is then fabricated to a carbide shank and the drill geometry is ground to produce a finished drill. Present costs for these drills average approximately $300 each.

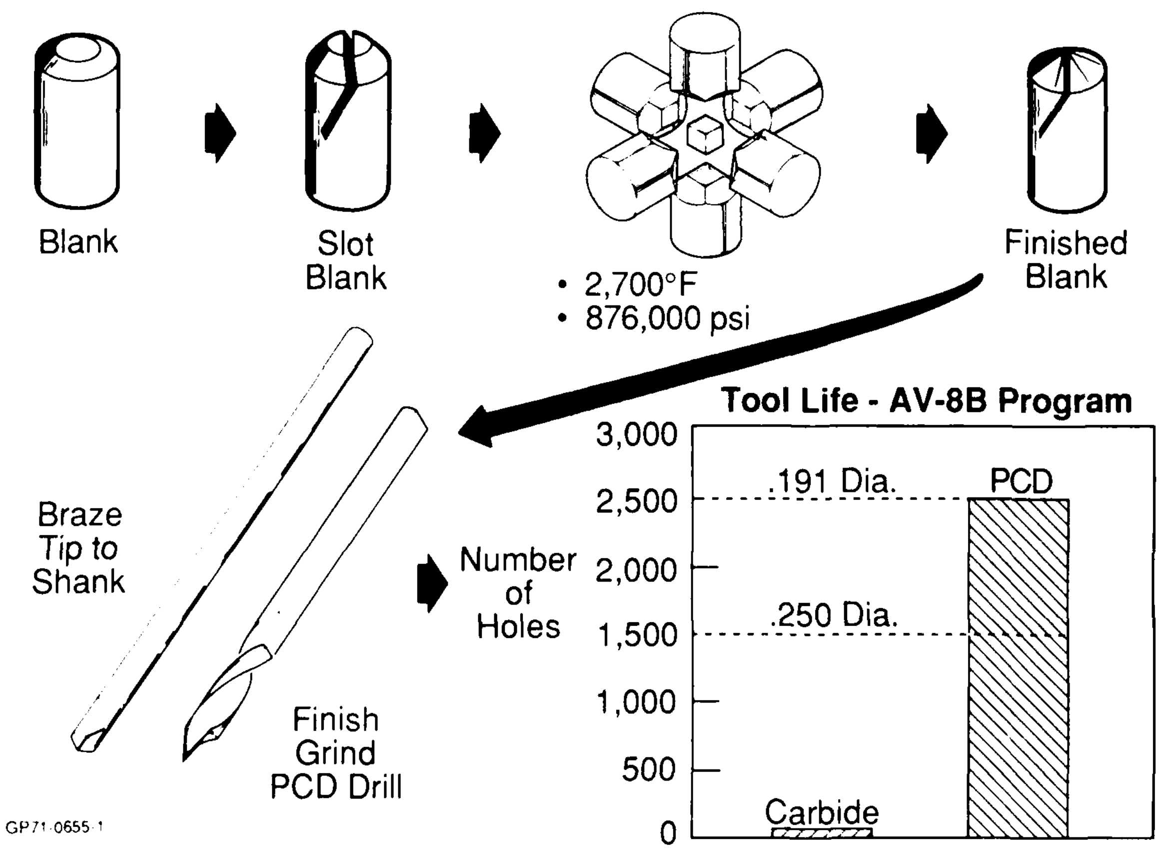

Figure 3.4-6: The Fabrication of Diamond Tipped Drills Provides the Capability of Drilling up to 2,500 3/16" Holes per Bit in Carbon-Epoxy Composite Material

AIR BEARING LINE DOLLIES FOR FINAL ASSEMBLY

MCAIR uses air bearing dollies on the F/A-18 and F-15 final assembly lines to move these aircraft through progressive workstations. The air bearing dolly is a three point load system using conventional aircraft jacks. Each of the three jacks has an air bearing located beneath it and are all tied together using steel framework. The air bearing dolly is assembled by Air Float Corporation.

The air bearing dolly uses 100 psi shop air to create pressure at each of the three air bearing pads. Air pressure is regulated individually at each pad. The dolly and aircraft are raised approximately 1/8" off the shop floor and are easily moved by three people. The steel framework acts as a back-up air chamber to slowly lower the aircraft in the event of a sudden loss of shop air pressure.

Floor surfaces must be smooth and level to provide easy and safe movement of the aircraft. MCAIR coated the shop floor with an anti-static epoxy compound produced by Garrett of Cleveland, Ohio, to achieve this smooth, level surface.

The air bearing dollies resulted in a 60% reduction in tooling cost over that of conventional final assembly line dollies. They also showed a six to one improvement in labor cost to load and unload aircraft from dollies and eliminated the use of cranes to remove a completed aircraft from a dolly.

Figure 3.4-7: The Air Bearing Line Dollies Allow Assembled Aircraft to be Moved Easily

AUTOMATED TUBING MANUFACTURING

MCAIR has been successfully applying computer technology to the design and fabrication of tubing for over ten years. The design engineer uses CADD to lay-out tube geometry by graphically routing the tube centerline through the aircraft structure and verifying the assembly fit. A software system called Formed Lines Using Interactive Data (FLUID) is used by the designer to specify tube physical characteristics. The tubes range in diameter from 1/8" to 4 1/2", with most tubes falling in the 1/4" to 3" range. This master tube design data is stored in a database for access by production planners and by Manufacturing personnel. A module called Tube Fabrication Information Sheet (TFIS) allows production planners to plan manufacturing methods and to add manufacturing parameters to the tube data. TFIS also creates a visual aid for the shop, which becomes part of the work order.

On the shop floor, a Vector Tube Measuring Machine (VTMM) takes coordinate data from the database, converts it to tube bend data, and incorporates tube spring back into the bend program. Automated tube benders use this data to form the tube. The formed tube is then compared to the master data on the VTMM. The VTMM also creates updated programs when measurements show that the tube exceeds allowable tolerances. This process eliminates mock-up tubes, has reduced set-up and run-time by about 50%, and greatly reduces scrap.

MDC is installing an automated tube preparation system. It is a computer controlled system that will automatically select the proper tube from stock on a storage rack, cut to the desired length, and end-finish. This system will combine multiple manual tube preparation operations into a single combined unit. It will provide more efficient shop loading capabilities and improve schedule control and quality while reducing labor costs, cycle time, cutting tool cost, and scrap. The system is produced by Eagle Manufacturing of Canada.

PREDICTIVE MAINTENANCE USING VIBRATION ANALYSIS

MCAIR is developing and testing predictive maintenance techniques for use on advanced machining systems such as the Automated Drilling System (ADS). A main focus of predictive maintenance has centered around the use of vibration analysis, which involves conductive wave form checks of the machine tools. The vibration analysis equipment is hooked up to the spindle of a machine tool and the machine tool is put through a test run at various speeds. When charted, the resulting information creates a normal operating signature for each machine tool.

Periodic checks of the machine tools with the vibration analysis equipment will show when a machine may be heading for some unexpected down-time. The vibration analysis graph will show sharp spikes, indicating increased vibration in the spindle. At this time, the spindle would go through a thorough check by maintenance craftsmen to determine the cause of the problem.

Vibration analysis was able to predict faults in the ADS slave bolt installer, which had been a major cause of cell down-time. It is ideal for monitoring advanced equipment and correcting minor fluctuations before they cause major problems. Since the vibration analyses have been conducted on the ADS, machine availability has averaged 96% on a three-shift schedule. Virbration Analysis has also identified machine design problems, which have been corrected on subsequent orders for similar equipment.

CAD FOR PLANT LAYOUTS

The MDC Graphics Design System (GDS) is a huge database, which supports facilities engineering. GDS resides on a Prime 6350 mainframe supporting 103 terminals, of which 53 have full graphics capabilities. The system currently contains over 1.5 million records. Each record contains graphics data of plant layouts showing furniture and machine locations; complete mechanical, electrical, and structural plans; land survey and contour data; and other detailed information on all MDC properties in St. Louis.

Facilities management personnel use the GDS to design improvements, plan changes, and manage all facilities requirements efficiently and accurately. GDS has been in operation for about three years. It runs on MDC developed software.

3.5 LOGISTICS

INTEGRATED CALS SYSTEM

MCAIR Product Support Division is developing an integrated Computer Aided Logistics Support (CALS) system, which is providing the information resources to support MCAIR products for decades to come. CALS is a cooperative effort between DOD and industry aimed at creating logistics information once, storing it once, and then using it wherever needed many times over. The CALS capability is being implemented on the A-12 program initially, and on existing programs on a progressive, incremental basis. It not only serves the customer's requirements, but is also providing user-friendly automated tools for MCAIR personnel of many disciplines.

The system consists of a common database integrated with modular application subsystems. The common database design and systems development emphasis is on providing shared data resources to support multiple processes, functions, and organizations. This data driven approach ensures integration of data resources and results in improved quality and productivity of many kinds of processes and functional elements.

One of the modules driven by the database handles logistic support analysis tasks such as the preparation of maintenance factor work sheets, level of repair analyses, provisioning of parts, and training analyses functions. Another module called Automatic Composition System/Computer Aided Technical Illustration (ACS/CATI), provides a near real-time system capable of integrating text and graphics to produce a fully composed technical publication.

ACS provides the capability to control the entire process of the technical publication; directly input, edit, and compose the manuscript with little knowledge of typesetting skills; produce a manual with little dependence on supporting personnel; and review and edit text and graphics. The CATI is being used by illustrators to work on CAD model blueprints. These so called "early bird" prints are constructed in a manner that satisfies the needs of engineering, manufacturing, and product support.

When illustrations are required for use in technical manuals, the "early bird" prints can be used to produce the illustrations with a minimal amount of modification. The "early bird" program starts the technical manual preparation process early in the development cycle.

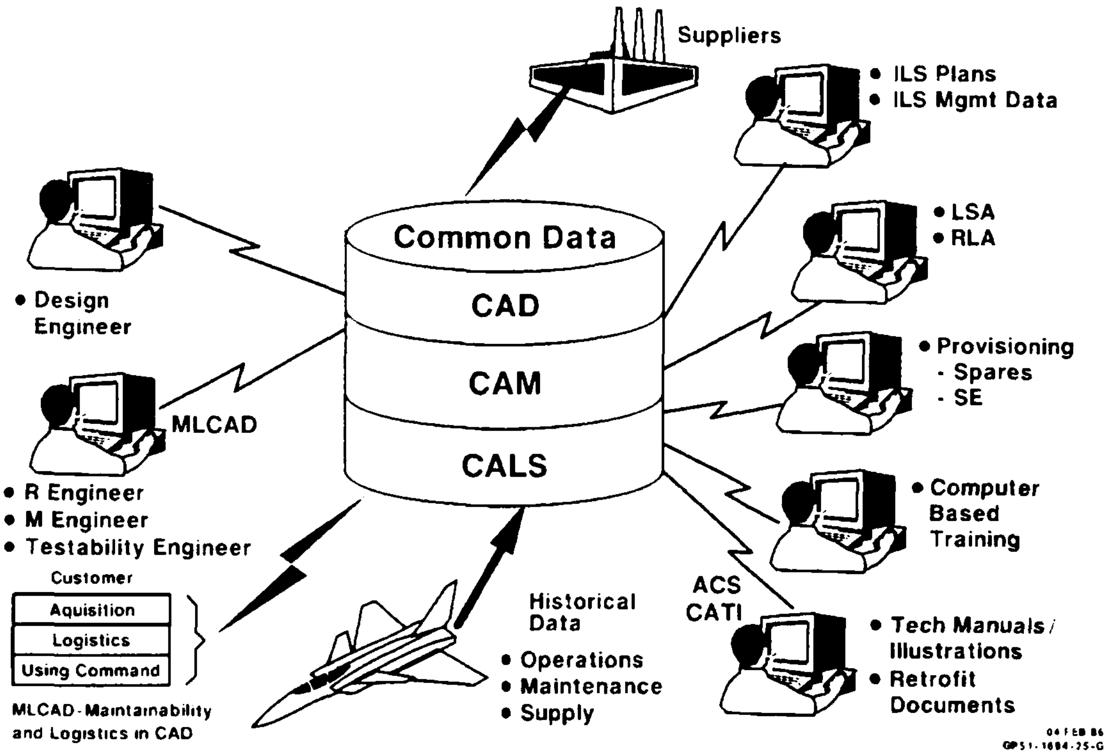

Figure 3.5-1: The Shared Database Concept Allows Logistics Information to be Created Once, Stored Once, and Used Many Times in the Life Cycle of the Product

ON-LINE CUSTOMER ACCESS TO MCAIR LOGISTICS DATABASES

During the spare parts provisioning process, MCAIR creates extensive databases that reflect the prime systems design and resulting logistics data. MCAIR has encouraged its customers to access this data via on-line means to reduce the ever increasing amount of paper associated with weapon systems. Supportability is increased and better organizational communication is attained. The customers utilize the data in their day-to-day decision making process, such as parts sourcing, part availability, and other logistics decisions that would normally be made using non-on-line access means, such as telephone calls, telexes, and other forms of inquiry to the contractor facility. The system is in use with the Navy Aviation Supply Office, Philadelphia, Pennsylvania, and with Warner-Robins Air Force Logistics Center in Warner-Robins, Georgia.

ON-LINE SPARE PARTS REQUISITIONING

The spare parts ordering process currently used depends heavily on a paper process. MCAIR encourages its customers to utilize an on-line requisitioning process whereby the solicitations and orders are processed by electrical digital transfer of data. Initial implementation with the Navy Aviation Supply Office, Philadelphia, Pennsylvania, and with Warner-Robins Air Force Logistics Center are well along. Advantages of the system include a reduction of direct labor costs associated with printing, stuffing envelopes, mailing, postage, telephone/telex, and courier expenses. Indirect reduction of costs include such factors as lowered safety stock due to shortening of the order cycle, reduction of clerical errors, and improved service.

3.6 MANAGEMENT

WORK FLOW PROGRAM

The Advanced Work Flow and Business Management System project (Work Flow) is being conducted to implement MDC's Total Quality Management System. The project started in July 1987.

The Work Flow strategic vision is to create a continuous flow of information and material from detail product design through delivery to the customer. The goal is that the resulting products would be of the highest quality, on time, and at the lowest possible cost. With this vision in mind, MCAIR assessed its internal operations and measured how well it was responding to customer requirements. Additionally, the local NAVPRO and the Defense Contract Audit Agency provided further focus for improvement initiatives. The findings of the assessments and the customer input were combined with other initiatives taking place across the company to yield a strategic Continuous Improvement Plan. This document defines the future state, sets forth transition paths, and establishes milestones. An important characteristic of the Continuous Improvement Plan is its own vulnerability to being changed.

The Plan relies on the following work flow principles for altering the ways MCAIR acquires and administers its business, defines its products, and builds and supports those products.

* Continuous flow of information and material.
* Total quality management (embedding quality into the process).
* Total cost management (improving accountability by converting to activity driven costing principles).
* Employee involvement (enhancing the work environment, changing traditional manager versus employee roles, and modifying the company structure to support process orientation and high performance teams).

The process is work flow driven and considers the total picture from the acquisition of business to after sale support. The major elements are:

* A collaborative product and process definition between design and manufacturing.
* Horizontal process integration across functions at all levels.
* Major improvements in both material management and accounting.
* Reduced production cycle time.
* Continuous flow manufacturing.

TOTAL QUALITY MANAGEMENT SYSTEM

The MCAIR Total Quality Management System (TQMS) is the implementation of MDC policy on total quality management. This system has top level management support, both at corporate headquarters and at MCAIR. TQMS simply defines the corporate and MCAIR way of doing business. It consists of three major parts:

* People/Teams/Partnerships.
* Disciplined systems and processes.
* A supportive cultural environment.

These three areas are sufficient and necessary to support the corporate goal of quality affordable products that satisfy its customers' needs. The system, as structured by MCAIR, represents classical Deming theory and contains elements from all of his 14 points.

The TQMS is a company-wide effort. Different parts of the program are progressing at different rates. MDC has made impressive efforts in communication, education, and establishing a viable working partnership between management and the labor union. In general, the employees seem enthusiastic about the new way of doing business.

Figure 3.6-1: MCAIR's TQMS Supports the Corporate Goal of Quality Affordable Products that Satisfy Customer Needs

CELLULAR MANUFACTURING: COMPOSITES

MCAIR has established a cellular manufacturing approach with good productivity results. One composite parts manufacturing cell reports 104 weeks of on-time delivery of quality parts. Cellular production has reduced quality problems by 50% and is consistently within budget. Cells are grouped by part size and complexity.

The cell operates as a team, established at the shop floor level. A multi-discipline management team supports the team. Team members can request permanent support people (i.e., tooling, quality, and production control). Management provides the requested support. Management operates by suggestion and guidance, not by edicts and firm, fixed schedules. The cell team can stop production and meet to solve problems. Changes are as easily initiated from the floor as from engineering. The team can determine, within reason, part mix and sequence to group similar parts in smaller quantities at frequent intervals. This maintains schedules, improves productivity. The Teams have actually developed long range plans and goals for the cell.

This is a true team approach. Shop floor production employees, foremen, support personnel, and managers are operating as a closely knit group. Production people have considerable latitude in day-to-day operations. They not only help each other, but are cross-training themselves. Vacations by individuals have little effect on production. The ability and freedom to be flexible where schedules and assignments are concerned are major contributors to success. Total management involvement and a coaching attitude support this. Each employee feels that he/she has a responsibility for cost effective quality production and is free to make suggestions knowing that they are being considered seriously.

A second production facility in a different building has carried the team approach one step further by including the finishing (autoclave and trimming) operations in the team. In this team, the person loading the curing fixture also unloads it, reducing tool rework to almost zero. This team includes the general foreman and several other foremen and crews.

CELLULAR MANUFACTURING: MACHINING

MCAIR has established several manufacturing cells to produce a wide variety of parts within the machining center. One of the most effective of these cells is the one dedicated to small turned parts.

The cell consists of two major DNC turning centers. There are also several other pieces of support equipment located within the cell. The cell operates on a three shift basis and is completely self-managed with no direct supervision. There are four operators on day shift, three operators on swing shift, and two operators on night shift. These operators are responsible for all work assigned to the cell including scheduling and setting-up and operating the machines necessary to produce the parts from raw stock to finished part. The operators are also responsible for inspecting the finished part, maintaining production schedules, and monitoring the quality and cost of finished goods. They participate in the selection of the parts that are assigned to the cell and are currently responsible for 248 part numbers. Of the parts currently assigned to the cell, the number of operations has been reduced from 22 to 9. The average cycle time has also been reduced from 27 days to 5 days.

Ownership for the work assigned and performed by the cell has been achieved by getting everyone involved in the process and giving them the responsibility and authority to initiate changes that improve the finished product. When parts leave this cell, all machine work is complete and meets the quality requirements and specifications of the drawing.

USE OF DEDICATED MAINTENANCE CREWS

MCAIR has found that when a sophisticated production machine has a problem, it sometimes takes maintenance too long to become familiar with the equipment and to diagnose and repair the problem. This is particularly true with advanced systems such as the Automated Drilling System.

MCAIR is in the process of introducing a dedicated maintenance crew concept. The crew is permanently assigned to a particular system and is charged with performing all of the preventive maintenance on the system. The crew becomes very familiar with the equipment assigned to it and is much more proficient at repairing it when there is a problem.

MCAIR feels that this technique has reduced machine down-time and is in the process of expanding this practice.

CAD/CAM TRAINING

MCAIR makes use of user and management training to support its CIM efforts. Both forms of training are developed in-house with an emphasis on the MCAIR CADD software.

The user training is modular and matches the various CADD applications software. This approach provides maximum training flexibility. Basic levels of user training are automated using the MCAIR Interactive Video Information System (IVIS). IVIS is hosted on stand-alone DEC PRO 350 personal computers augmented with video disc players. The IVIS system is both self-paced and self-introducing. More advanced user training is provided on the CADD system. Typically, four users are trained by one experienced user with proficiency in that particular CADD application.

Management training consists of a combination of management overviews in various formats, hands-on exposure, and plant tours. The training has been widely applied using a top-down approach starting with engineering vice president and program management personnel. The program provides increased awareness of the CIM environment including related technologies and capabilities.

MANAGING CULTURAL CHANGE: COMMUNICATIONS

Employee surveys indicate the desire for improved communications with management. MCAIR has addressed this desire in a multi-media environment involving the very highest levels of company management.

A bi-monthly newsletter titled "Team Talk" consists of eight to 24 pages and has a circulation of 41,000 current and retired employees. "Team Talk" is mailed directly to the employees' homes, and contains articles of interest for all members of the family as well as articles on the new ways of doing business. MCAIR has also developed and issued a pocket card listing the MCAIR Strategic Business Objectives. This allows all employees to be informed on the direction the company is going.

Once a week, the president of MCAIR makes a two to three minute speech on the public address system. This talk is also available by dialing a special telephone number.

Team Talk Live is a management - employee live exchange that takes place twice a year and involves the highest levels of management and 350 to 400 randomly selected employees. The format for the exchange is 1/3 management presentation and 2/3 questions and answers. This series of exchanges is video taped and distributed throughout MCAIR.

There have also been a series of meetings involving the Executive Vice President of Operations and small groups of management and supervisory employees. These meetings occurred three times a week and lasted one hour. To-date, they have met with 1,000 people.

MANAGING CULTURAL CHANGE: TEAM BUILDING

Many of the Total Quality Management System concepts require intense employee involvement and commitment. MCAIR has addressed this problem through a series of initiatives based on team building, which establishes a strong link between the supervisor's execution of his leadership role and the business goals of the company.

An example of team building is cellular manufacturing, which is based on organizing manufacturing around the natural work group. This enhances the team concept because all cell members are involved in producing families of small parts and similar assemblies. This cellular arrangement provides the environment necessary for direct worker involvement and increasing levels of self-management and control. Employee enthusiasm for this is demonstrated by improved quality, reduced costs, and schedule compliance.

Taking this concept one step further is a pilot program in self-managed work areas. In this program, shop personnel are given authority and responsibility for quality and productivity within their area. They are self-supervised with a general foreman on call if they need help. Cell members attend budget meetings as a team and solve their day-to-day problems of mix, quality, schedule, etc. (This program is described in another part of this report.)

MANAGING CULTURAL CHANGE: EDUCATION/TRAINING PROGRAM

MCAIR has instituted a vigorous program of education, training, and self-improvement.

Some examples of this are as follows:

* The Executive Automation Education Program. The purpose of this program is to aid management in leading the change in culture to digital information. It is targeted at engineering management level personnel (Vice President of Engineering, MCAIR Program Managers, Division Heads, etc). It totals 16 hours of presentations, demonstrations, videos, discussion, hands-on and plant tours. To-date there have been 12 classes with 145 people completing the course; there is a backlog of 92 people waiting to take the course.

* Team building training focuses on the natural work group and its supervisor and is tailored to the needs of the specific group. Team building assists the team in areas such as development of a vision, mission, and values statements; organization restructure and redesign; conflict resolution; communication skills; decision making; problem solving; etc. It also provides consulting to individual supervisors on leadership practices.

* Employee retraining. Where reorganizations eliminate positions and no further jobs exist in those particular trades, employees may be retrained into a different trade.

* A training program for first line and middle management based on a competency model for successful management at MCAIR. The targeted managers may receive training in those competency areas where they need strength or where they need to broaden their knowledge base.

MCAIR has under development a voluntary program that takes place after hours for those employees who wish to enter production supervision. It will involve development of specific skills through tailored college level courses and existing MDC courses and workshops.

PRESENTEEISM PROGRAM

The Presenteeism Program recognizes individual employees for perfect attendance. The program was implemented in 1984 to increase productivity and heighten awareness of good attendance in a positive manner. It consists of two parts:

* Drawings for Trips and Cash Awards. Eligibility for the drawings is the same for everyone and is based on a six-month perfect attendance record. There are two drawings held each year. At each drawing, the names of three employees are selected to receive an all-expenses paid trip for two (or $2,500) plus eight additional vacation days. An additional eighteen names are drawn to receive a cash award of $1000, $1500, or $2000 depending upon the years of perfect attendance. Fifty additional employees receive $100 each. MCAIR pays the taxes on all of the prizes.

* Annual Recognition Awards. Eligibility is determined by perfect attendance for a twelve month period based on each individual employee's sick leave anniversary date. This year of recognition is based on the total of non-consecutive years of perfect attendance as a MCAIR employee since the beginning of the program (January 1984). The award recipients receive annual recognition awards up to $100 and a certificate and badge extender specifying the number of years of perfect attendance. Each block of five consecutive years nets an additional $200.

The success of the program is impressive and is depicted below:

Year	Days Absence/Employee	% Perfect Attendance
1984	4.0	14.3%
1985	3.1	28.7%
1986	2.7	35.7%
1987	2.8	40.3%
1988 (through 3rd Quarter)	2.1	45.4%

QUALITY, SCHEDULE, AND COST REPORT

MCAIR had developed a supplier status report. The one page report is current within 24 hours, and shows cost, delivery, and quality on every major component supplier.

The resulting data can be viewed on graphic terminals or printed as hard copy on text terminals. Data is gathered and stored on a regular basis and lists failures, problems, and rejections as well as overall cost trends, inventory, and schedule status.

SYSTEMS DEVELOPMENT, PRODUCTION, AND SUPPORT MANUAL

The MDC Systems Development, Production, and Support Manual was developed in order to assist MDC program managers in structuring sound programs and identifying areas needing corrective action. The manual is structured similarly to DOD 4245.7M "Transition from Development to Production." The major thrust of the manual is to help identify critical processes and their control methods.

The manual is intended to help program managers implement and tailor customer policies and initiatives such as:

* DOD 5000.43 "Acquisition Streamlining"
* DOD Initiative "Model Contractor and Could Cost"
* DOD Initiative "Total Quality Management
* DOD 4245.7M "Transition from Development to Production"
* AMC Reg 702-XX "Contractor Performance Certification Program"
* NAVSO P-6071 "Best Practices"
* USAF "R&M 2000 Process"

MCAIR has improved the effectiveness of this manual by tying it to a series of training courses. These courses are provided to entry level personnel through middle management and various levels of upper management. The courses develop both an awareness of these programs and their benefits and establish an educational base for their application and implementation.

SECTION 4

PROBLEM AREAS

4.1 DESIGN

COMPUTATIONAL FLUID DYNAMICS

The Government can play a significant role in improving the value of Computational Fluid Dyanmics (CFD) to the aerospace and defense industries. Standards are needed in the following areas: data format, grid generation methods, and geometry definition. In addition, the Government should join with industry to develop experimental and CFD validation studies for realistic engineering problems (3D, complex geometry, wide speed range). An annual industry/government symposium is needed where information could be exchanged on CFD needs, perceived problems, and corrective actions.

4.2 PRODUCTION

IMPACT OF THE FEDERAL CLEAN AIR ACT

The Federal Clean Air Act impact on MCAIR has been significant, and has the potential to be disruptive and costly. MCAIR is currently in compliance. However, the inconsistencies between the six Federal Environmental Acts and the differences between the federal acts have resulted in problems for the facilities of MDC that are located in states other than Missouri (especially California). Another troublesome factor is that environmental regulations require compliance to directed changes in as few as five months. In addition, it is anticipated that future legislation will result in tighter emission requirements.

MCAIR has particular problems with coatings and coating solvent emission. MCAIR has addressed this problem area and has reduced overall plant emissions from 900 tons per year in 1979 (110 aircraft) to 525 tons per year in 1984 (151 aircraft). MCAIR's philosophy is that waste treatment and disposal always increase costs and that proactive technology development and implementation can improve quality, performance, and costs.

To accomplish compliance and to mitigate future problems, MCAIR has established a corporate environmental program. At the corporate level, a Director of Environmental Compliance, a legal advisor, and a toxologist have been appointed. Engineering and facilities focal points have also been established. MCAIR is also sharing data and looking for solutions to common problems with respect to chromium with other companies.

MCAIR has decided to protect its interests by identifying areas where work needs to be done. These are:

* Provide input to regulatory agencies.
* Actively pursue, test, and implement low emission materials.
* Adoption of control technology where other alternatives are not possible.

APPENDIX A

TABLE OF ACRONYMS

Acronym	Definition
2D	Two Dimensional
3D	Three Dimensional
ACCESS	Automatic Control and Checking for Electrical Systems Support
ACS/CATI	Automatic Composition System/Computer Aided Technical Illustration
ADPLS	Automated Drawing Parts List System
ADS	Automated Drilling System
AFSA	Automated Finish Selection Advisor
AFSS	Aircraft Fastener Selection System
AGTS	Advanced Group Technology System
AI	Artificial Intelligence
AMPS	Automated Mass Properties System
AMRF	Automated Manufacturing Research Facility
ANSI	American National Standards Institute
AP/SAP	Advanced Pitot/Static Air Pressure
APT	Automatic Programmed Tool
ATF	Advance Tactical Fighter
ATO	Automated Tooling Order
AUSS V	Automated Ultrasonic Scanning System V
BIT	Built-in-Test
BLATS	Built-up Low Cost Advanced Titanium Structures
BMP	Best Manufacturing Practices
BMP-MIS	Best Manufacturing Practices Management Information System
CAD	Computer Aided Design
CADD	Computer Aided Design and Drafting
CAE	Computer Aided Engineering
CALS	Computer Aided Logistics Support
CAM	Computer Aided Manufacturing
CAMI	CAM-International
CAQA	Computer Aided Quality Assurance
CATI	Computer Aided Technical Illustration
CATIA®	Computer-Graphics Aided Three Dimensional Interactive Applications ®Dassault Systems
CCS	Composite CAM Systems
CEEDS	Common Electrical/Electronic Data System
CFD	Computational Fluid Dynamics
CGM	Computer Graphics Metafile
CGSA	Computer Graphics Structural Analysis
CIM	Computer Integrated Manufacturing
CMM	Coordinate Measuring Machine

Acronym	Definition
CNC	Computer Numerically Controlled
COLLIDE	Collision Separation Distance Calculation Program
CPU	Central Processing Unit
DNC	Direct Numerical Control
DOD	Department of Defense
DPM	Digital Product Model
DTP	Decision Table Processor
EARRS	Engineering Automated Release and Record System
EDF	Electronic Development Fixture
EDM	Electronic Discharge Machine
EMPF	Electronics Manufacturing Productivity Facility
FACT	Federation of Automated Coding Technologies
FLUID	Formed Lines Using Interactive Data
GDS	Graphics Design System
GPPS	Generative Process Planning System
ICC	Integrated Composites Center
IGES	Initial Graphics Exchange Specification
IMIP	Industrial Modernization Incentives Program
ISAP	Integrated Structural Analysis Package
ISS	Integrated Scheduling System
IVIS	Interactive Video Information System
IWAP	Interactive Weight Accounting Program
JIT	Just-in-Time
LAN	Local Area Network
LOAPS	Large Order Assembly Planning System
MAP/TOP	Manufacturing Automation Protocol/Technical and Office Protocol
MCAIR	McDonnell Aircraft Company
MDC	McDonnell Douglas Corporation
MDI	Manual Data Input
MSC-NASTRAN	MacNeal Schwendler Corporation version of NASTRAN
MTI	Metalworking Technology, Incorporated
MTN	Metropolitan Transport Network
NASA	National Aeronautics and Space Administration
NASTRAN	NASA Computer Program for Structural Analysis
NAVPRO	Naval Plant Representative Office
NC	Numerical Control
NCIMS	Numerical Control Information Management System
NDI	Non-Destructive Testing
OSAR	Optical-Disk Storage and Retrieval System
PATRAN	PDA Corporation version of NASTRAN
PCS	Parts Control System

Acronym	Definition
PDDI	Product Definition Data Interface
PDDS	Product Design Data System
PDES	Product Data Exchange Standard
PMDS	Portable Machine Diagnostic System
QC	Quality Control
QUIC	Quality Interpretation Center
RAPID	Remote APT Processing via Interactive Devices
SDF	Six Degrees of Freedom
SEESEP	Stores Separation Distance Display
SPC	Statistical Process Control
SPF	Superplastic Forming
SPF/DB	Superplastic Forming/Diffusion Bonding
SSIP	Stores Separation Investigation Package
STAFS	Special Tool Accountability, Fabrication, and Storage
STOL	Short Take-Off and Landing
TARS	Turnaround and Reconfiguration Simulation
TCM	Tool Crib Management
TDU	Triaxial Detector Unit
TFIS	Tube Fabrication Information Sheet
THAD	Time History Animation Display
TQMS	Total Quality Management System
TSO	Time Sharing Option
VTMM	Vector Tube Measuring Machine
WORM	Write-Once-Read-Many
WTDS	Wind Tunnel Data System

APPENDIX B

BMP REVIEW TEAM

Team Member	Agency	Role
Leo Plonsky (215) 897-6686	**Naval Industrial Resources Support Activity** Philadelphia, PA	**Team Chairman**
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Ernest Screen (301) 227-1350	**David Taylor Research Center** Bethesda, MD	
Kevin Wilson (301) 267-3385	**David Taylor Research Center** Annapolis, MD	
Wayne Koegel (202) 692-6025	**Naval Air Systems Command** Washington, DC	
Thomas Crosby (301) 863-1660	**Naval Air Test Center** Patuxent River, MD	
Richard Engle (317) 353-7844	**Naval Avionics Center** Indianapolis, IN	
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Jack Tamargo (707) 646-2137	**Mare Island Naval Shipyard** Vallejo, CA	
Simon Frechette (301) 975-3335	**National Institute of Standards and Technology** Gaithersburg, MD	
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Roland Cochran (215) 441-2649	**Naval Air Development Center** Warminster, PA	

Team Member	Agency	Role
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Gaylen Fischer (309) 782-6718	**U.S. Army Industrial Engineering Activity** Rock Island, IL	
John Fickers (505) 667-3728	**Los Alamos National Laboratory** Los Alamos, NM	

APPENDIX C

PREVIOUSLY COMPLETED SURVEYS

BMP surveys have been conducted at the companies listed below. Copies of survey reports for any of these companies may be obtained by contacting:

Best Manufacturing Practices Program
Office of the Assistant Secretary of the Navy
(Shipbuilding and Logistics)
Attn: Mr. Ernie Renner, RM&QA
Washington, DC 20360-5000
Telephone: (202) 692-0121

COMPANIES SURVEYED

Litton
Guidance & Control Systems Divison
Woodland Hills, CA
October 1985

Honeywell, Inc.
Underseas Systems Division
Hopkins, MN
January 1986

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

General Dynamics
Pomona Division
Pomona, CA
August 1986

Harris Corporation
Government Support Systems Division
Syosset, NY
September 1986

IBM Corporation
Federal Systems Division
Owego, NY
October 1986

Control Data Corporation
Government Systems Group
Minneapolis, MN
December 1986

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

ITT
Avionics Division
Clifton, NJ
September 1987

Rockwell International Corporation
Collins Defense Communications
Cedar Rapids, IA
October 1987

UNISYS
Computer Systems Division
St. Paul, MN
November 1987

Motorola
Government Electronics Group
Scottsdale, AZ
March 1988

General Dynamics
Forth Worth Division
Fort Worth, TX
May 1988

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

Hughes Aircraft Company
Missile Systems Group
Tucson, AZ
August 1988

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

Litton
Data Systems Division
Van Nuys, CA
October 1988

GTE
Government Systems Corporation
C^3 Systems Sector
Needham Heights, MA
November 1988

Information gathered from all BMP surveys is included in the Best Manufacturing Practices Management Information System (BMP-MIS). Additionally, a calendar of events and other relevant information are included in this system. All inquires regarding the BMP-MIS may be directed to:

Director, Naval Industrial Resources Support Activity
Attn: BMP-MIS System Administrator
Bldg. 75-2, Room 209, Naval Base
Philadelphia, PA 19112-5078
Telephone: (215) 897-6684

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Washington, D.C. 20360-5000

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The purpose of the Best Manufacturing Practices (BMP) survey conducted at this facility was to identify their best practices, review manufacturing problems, and document the results. The intent is to extend the use of progressive management techniques as well as high technology equipment and processes throughout the U.S. industrial base. The actual exchange of detailed data will be between contractors at their discretion. A company point of contact is listed in the report

The intent of the BMP program is to use this documentation as the initial step in a voluntary technology sharing process among the industry.

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