*REPORT OF SURVEY CONDUCTED AT*

# BELL HELICOPTER TEXTRON, INC.

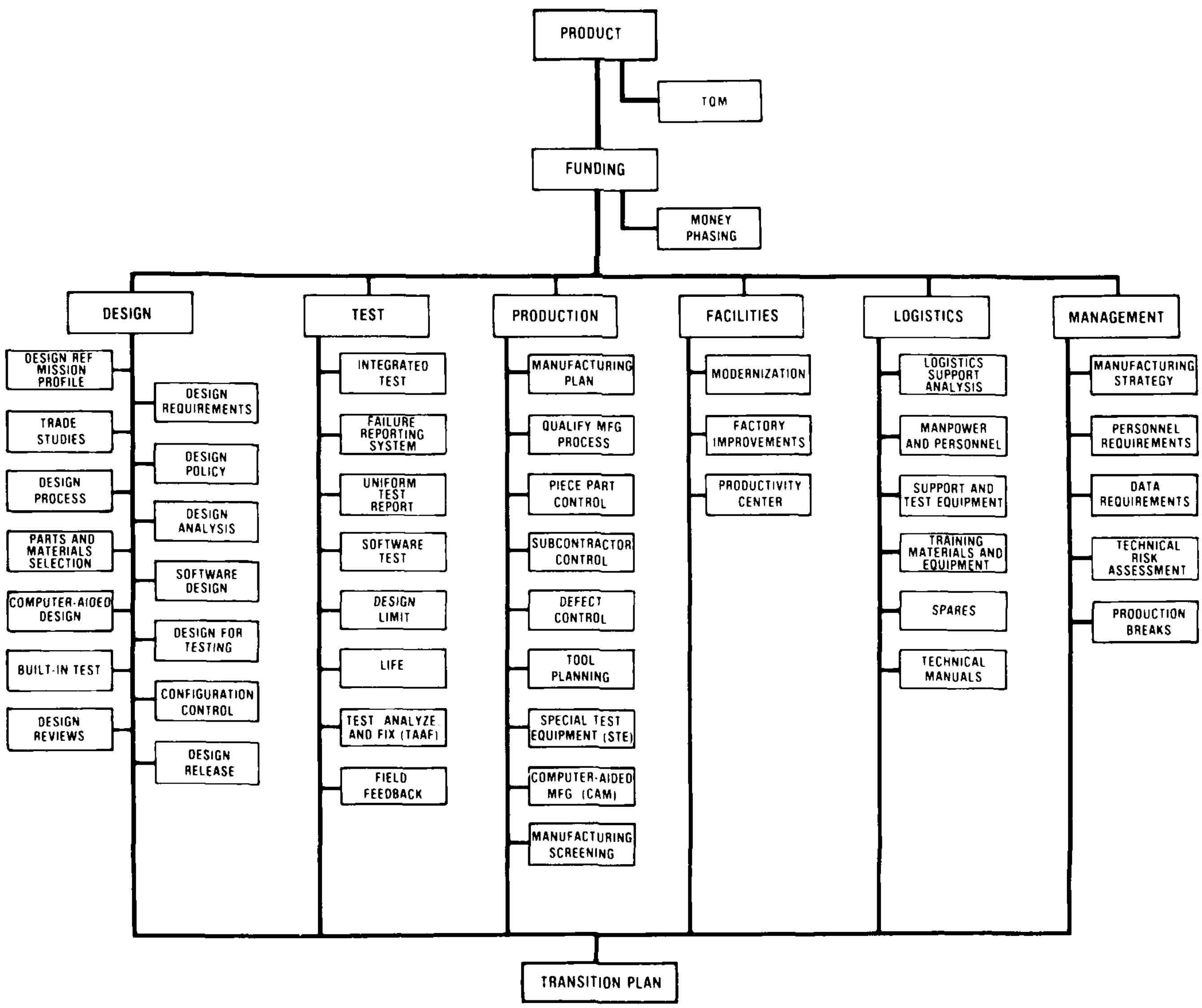
FORT WORTH, TEXAS

*OCTOBER 1988*

# DoD 4245.7-M

# "TRANSITION FROM DEVELOPMENT TO PRODUCTION"

## CRITICAL PATH TEMPLATES



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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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# CONTENTS

# CONTENTS (Continued)

# CONTENTS (Continued)

# FIGURES

# SECTION 1

# EXECUTIVE SUMMARY

The Best Manufacturing Practices (BMP) team conducted a survey at Bell Helicopter Textron, Inc. (BHTI) during 11-14 October 1988. The purpose of the survey was to review and document the best practices and potential industry-wide problems at BHTI. 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 BHTI facility in Fort Worth, Texas. These facilities produce several different helicopter models and are actively engaged in a teaming arrangement with Boeing - Vertol Division on the initial production of the V-22 TiltRotor airplane.

## 1.1 KEY FINDINGS

There were many best practices observed at Bell Helicopter Textron, Inc. and detailed in this report. Some of the more significant findings included in this report are summarized below:

| Item | Page |
|---|---|
| Bell Engineering Information Management System<br>An engineering database that effectively controls the release of engineering information and maintains configuration control. | 7 |
| Stress Analysis Techniques<br>Photoelasticity and thermal image analyzer are used by design engineers to effectively analyze effects of stress. | 8 |
| Detection of Backing Material Inclusion<br>An new early detection approach is described. | 13 |
| Programming of Coordinate Measuring Machines<br>Downloading of CAD data eliminates the need to "teach" program the CMM. | 14 |
| Cubic Boron Nitride Grinding<br>Provides increased accuracy and reduces cost. | 16 |
| Composites Manufacturing Techniques<br>Several innovative approaches in the use of composites materials are described. These include techniques and equipment for tooling, production, and inspection. | 18 - 20 |
| Wire Harness Automated Manufacturing System<br>Significantly streamlined the manufacturing of large wire harnesses. | 22 |

# SECTION 2

# INTRODUCTION

## 2.1 SCOPE

The purpose of the Best Manufacturing Practices (BMP) review conducted at Bell Helicopter Textron, Inc. (BHTI) was to identify best practices, review manufacturing problems, and document the results. The intent of these reviews 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, and NASA accepted an invitation from BHTI to review and document the most advanced manufacturing processes and techniques used in their facilities located in Forth Worth, Texas. The review was conducted on October 11-14, 1988 by the team identified in Appendix B of this report. BHTI is engaged in the production of several different helicopter models and is actively engaged in a teaming arrangement with Boeing - Vertol Division on the initial production of the V-22 TiltRotor airplane.

The results of BMP reviews are being 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 central computer. The actual exchange of detailed technical data will take place between contractors at their discretion on a strictly voluntary basis.

The results of this review should not be used to rate BHTI 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 REVIEW PROCESS

This review was performed under the general survey guidelines established by the Department of the Navy. The review concentrated on the functional areas of design test, production, facilities, management, and logistics. The team evaluated BHTI'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." BHTI 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:

* Automated Manufacturing Research Facility (AMRF)
  Gaithersburg, MD

* Electronics Manufacturing Productivity Facility (EMPF)
  China Lake, CA

* Metalworking Technology Incorporated (MTI)
  Johnstown, PA

## 2.4 BELL HELICOPTER TEXTRON OVERVIEW

Bell Helicopter Textron, Inc., Fort Worth, Texas, is one of the leading producers of helicopters and spare parts for the U.S. Government, foreign governments, and civilian markets. More than half of all the helicopters operating in the free world are Bell Helicopters.

A wholly owned subsidiary of Textron Inc., BHTI is an integrated builder of rotary aircraft with the capabilities to produce virtually every component with the exception of engines and avionics. BHTI is a $1.1 billion (1987 revenues) company consisting of nine plants in Texas and one in Canada for a total of 3 million square feet of facilities and 9,300 employees.

Over the years, Bell has been, and continues to be, a prime helicopter supplier to the U.S. and other governments with the UH-1 Huey, AH-1 Cobra, TH-57 Advanced Trainer, and the OH-58D Advanced Scout. Presently, BHTI is co-developing the V-22 Osprey TiltRotor for the U.S. Navy/Marine Corps/Air Force. Due to fly in 1989, the V-22 can take off, hover, and land like a helicopter and fly forward with the range and speed of a turboprop airplane.

## 2.5 ACKNOWLEDGEMENTS

Special thanks are due to all the people at BHTI whose participation made this survey possible. In particular, the BMP team acknowledges the special efforts of Mr. Evan Blake who was instrumental in making this survey possible.

## 2.6 BELL HELICOPTER TEXTRON, INC POINT OF CONTACT

While the information included in this report is intended to be descriptive of the best processes and techniques observed at BHTI 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 BHTI 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 Bell Helicopter Textron, Inc.

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

Mr. Evan Blake
Chief, Manufacturing Development/
Special Projects
Bell Helicopter Textron, Inc.
P.O. Box 482
Fort Worth, TX 76101
(817) 280-4065

# 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 BHTI's efforts to reduce the life cycle costs of its products.

## *3.1 DESIGN*

### *BELL ENGINEERING INFORMATION MANAGEMENT SYSTEM*

The Bell Engineering Information Management System (BEIMS) is an automated database used for release and control of engineering information. The system contains a complete record of all engineering data. This includes detailed information on each drawing and part number, such as:

* Bill of materials
* Raw materials requirements
* Next assembly
* Alternate usage
* Vendor qualification
* Reference designators (electrical)
* Wire numbers (electrical)
* Release status
* Configuration control data
  - Configuration history
  - Effectivity of engineering changes

This database is integrated with several other systems such as CADAM, a computer aided planning system, and a wire harness and automated manufacturing system.

The efficiencies enjoyed by BHTI that resulted from the implementation of this system are derived from improved communications between engineering, manufacturing, purchasing and quality assurance. An accurate configuration management function is also a significant by-product of using the system.

### *COMPOSITE PLY PATTERN GENERATION*

BHTI is in the process of automating the process of composite ply perimeter generation. This process is accomplished through the use of component surface models. Surface information is created for each ply of the component using CATIA software. Flat patterns for the various plys are then automatically created from these models using BHTI developed software.

Perimeter data for the flat patterns created using CATIA software are translated into CADAM format. The CADAM data is used in a pattern nesting program, and to drive a Gerber Instrument composite fabric cutter.

This procedure significantly reduces the chance of errors and the time required to develop composite layer patterns. Good results have been achieved with ruled surfaces and compound curved surfaces. Flat pattern generation for complex surfaces is currently being investigated.

### *PHOTOELASTIC TECHNIQUE FOR STRESS ANALYSIS*

BHTI uses photoelasticity to evaluate stress levels and locate stress concentrations in geometrically complex parts. This technique allows the designer to quickly assess the effects of design changes. Although the photoelastic technique is not new, BHTI has continued to enhance this procedure while most of the industry has abandoned it in favor of finite element analysis. BHTI has developed an epoxy resin from which they mold and machine the test specimen. The part is subjected to the appropriate loading conditions and a final curing process is performed. The curing process locks the stress patterns into the specimen. The stress patterns can be observed through a polarizing filter which reveals fringe patterns. The magnitude of the stress can be quantified by cutting the specimen and comparing the stress patterns to a reference standard.

Although BHTI uses finite element analysis extensively, they have demonstrated the photoelastic technique to be faster and less costly in many cases. This method was compared to a million element finite element model in an accuracy comparison.

### *NON-CONTACT STRESS ANALYSIS*

A thermal image analyzer manufactured by Spate is used by BHTI as a non-contact stress analysis tool. A part is placed under cyclic loading and infrared detectors measure temperature changes over the surfaces of the part. The steady-state temperatures are filtered from the signal to reveal temperature variations over the part. These temperature variations directly correspond to stress fields on the surface of the part. This analysis tool enables the designer to identify stress concentrations and stress levels on the surface of complex parts and assemblies.

### *THE EFFECTS OF DEFECTS IN COMPOSITE MATERIALS*

BHTI has developed the ability to correlate ultrasonic inspection results to the mechanical properties of graphite/epoxy composite materials. They hope to use this information during the accept/reject decision-making process for composite parts that do not meet nondestructive inspection (NDI) acceptance criteria. This information may also be used to redefine the NDI acceptance criteria used for production parts.

BHTI's study of the "Effects of Defects" on composites may ultimately reduce part rejections by providing quantitative data to the material review board for use in the assessment of a part's structural integrity. Without a quantitative assessment of defects, every flaw must be considered potentially fatal.

Specifically, dispersed intralaminar porosity was investigated. It was found that porosity content varied linearly with ultrasonic signal attenuation in IM6/3501-6 laminates. Furthermore, interlaminar shear strength and open hole compression strength were shown to decrease linearly as ultrasonic attenuation levels increased. The initial studies of fatigue properties show a similar trend. Further investigations of fatigue properties will be performed in the future, as well as investigations of the effects of delaminations, marcels, and other defects.

## *CAT SCAN RADIOGRAPHY*

Computer Aided Tomography (CAT) scan radiography is being investigated by BHTI to inspect complex composite parts such as yokes and proprotor grips. CAT scans can be used to determine fiber misalignments and variations induced by the manufacturing process. In addition, they can also be used to find the typical anomalies which occur in composites, such as voids, porosity and delaminations, which can also be found with more conventional inspection methods. This makes CAT an extremely sensitive and versatile diagnostic tool that can aid engineering and manufacturing in both part design and process development.

Initial activity has involved the use of CAT scan facilities available at local hospitals. The 40 KVma output available at these facilities is more than adequate for inspection of composite parts up to four inches thick. Using these facilities, V-22 proprotor grips and sections of the yokes have been inspected. The results were used to modify the manufacturing processes and design in order to minimize marcelling and wrinkling which occur in these thick section parts.

The CAT scan will continue to be used as a design and manufacturing process development tool to further enhance product quality rather than an end item inspection method. The information gained from the use of available CAT scan facilities and results are being used to develop a requirements document and specification for the purchase of a CAT scan system by BHTI.

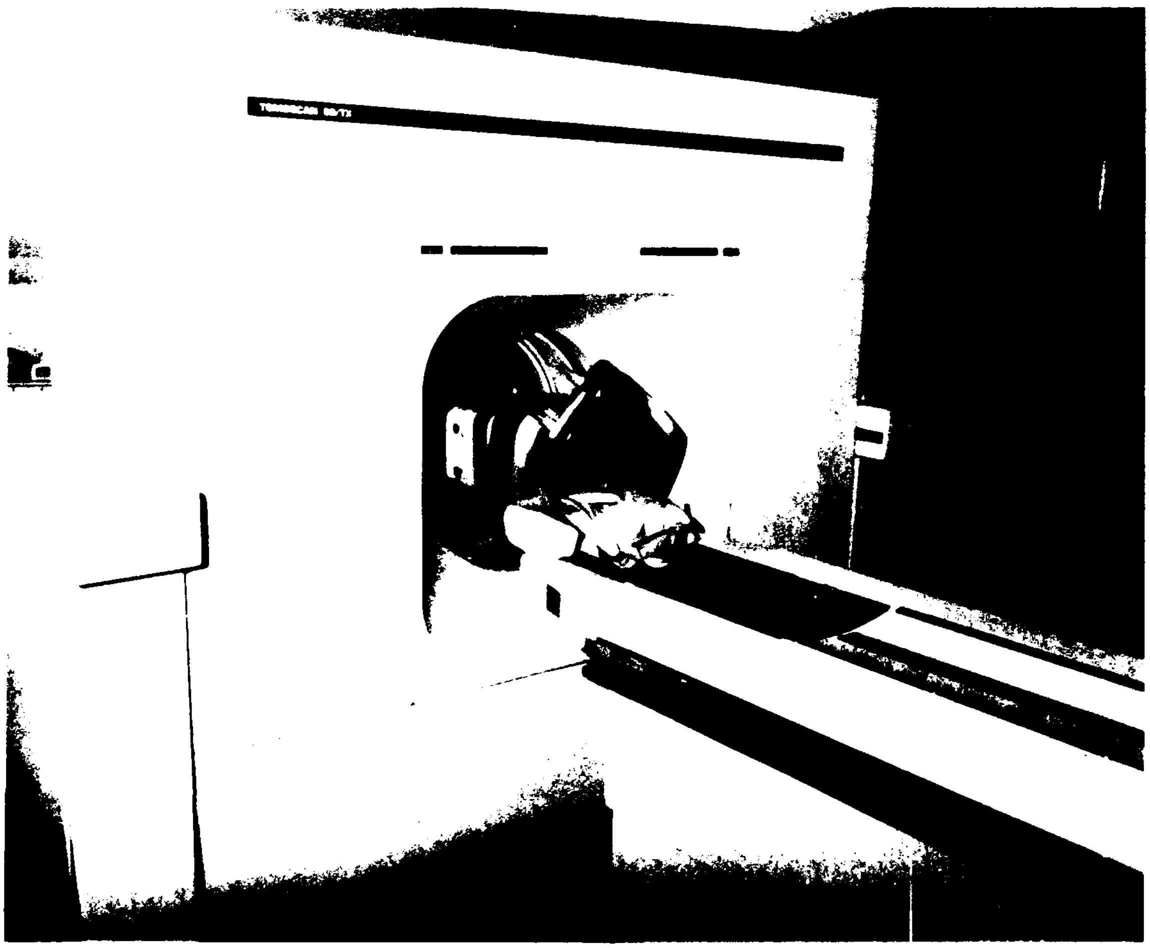

***Figure 3.1-1: V-22 Grip Being Inspected with CAT Scanner***

## 3.2 TEST

### ADAPTIVE FATIGUE TESTING

Fatigue testing of primary flight structures at BHTI is performed using the internally developed Automatic Fatigue Test Control System (AFTCS). The system acts as a controller, monitor, and data acquisition system.

Ideal displacement levels are established for various locations on the test article. Strain gauges are placed at these locations in order to provide feedback to the load controller. The test is initiated by placing a load of 10% on the specimen. If the displacement data returned by the feedback system agrees with predetermined results the cyclic loads are gradually increased to 100%.

As the test progresses, the system compensates for changes in the stiffness of the test article or for wear in the test fixture. The controller has a critical limit which if exceeded will stop the test. Exceeding the critical limits is the result of large strains or redistribution of loads which are indicative of crack initiation.

### TRANSMISSION ASSEMBLY AND TESTING

Transmission assembly at BHTI is principally a manual process based on a planned sequence of operations. This process is used on cases complete with liners and miscellaneous hardware, subassemblies including quills and planetaries, complete gearbox assemblies, and mast assemblies.

The V-22 proprotor, tilt-axis and mid-wing gear boxes are tested, disassembled, inspected, reassembled, and leak tested. Special fixtures are used to assist the mechanics in positioning and holding the components during this entire process. Test facilities include 19 production cells used for all production and spare components, and 12 development cells for development and qualification testing of current aircraft and V-22 components. The production test consists of a two hour acceptance test to assure proper assembly and the proper operation of all parts, including the lubrication system. Special closed loop mechanical test stands are used to generate full power simulation. These test cells include programmable controllers and data acquisition systems.

### GEAR AND CASE INSPECTION

BHTI designs utilize two basic gear types - parallel axes (spur and helical) and non parallel-axes (spiral bevel). These gears are manufactured to extremely tight tolerances and are inspected for stock removal, tooth profile, tooth spacing, root radius blend, surface finish, and hardness. Inspection techniques include nital etch, magnetic particle, ultrasonic evaluation, fluorescent penetrant, coordinate measurement machine (CMM), and gear run-in and tooth space measuring machines. Gearbox housings are inspected to verify proper positioning of gears and to ensure exact mounting surface dimensions and distances. A Zeiss UMM 800 CMM is used for gearbox case inspection.

### QUALITY MANAGEMENT SYSTEM

BHTI has developed a state-of-the-art computer based Quality Management System designed to provide a more efficient and effective means to document and analyze nonconforming products and services. Its objective is to reduce costs associated with nonconformances in scrap, rework, and repair along with costs associated with warranties, obsolescence, and troubleshooting. The system was brought on-line in

January 1988 and is currently in phase I of a phased development and implementation program. This program has been given top priority by BHTI senior management.

In its current form, the system does the following:

* Provides timely management information for problem solving and decision making;
* Enhances problem prevention through improved visibility of historical events;
* Baselines nonconformance costs and measures improvements;
* Prioritizes and tracks corrective action efforts;
* Rates vendor performance.

Features of the system include on line input, comprehensive editing, and automation of Material Discrepancy Reports (MDR) and rework instruction reports. Since all terminals and systems at BHTI are connected, it provides electronic interfaces between hundreds of QMS users. Numerous report formats are available at various levels showing defect costs, corrective action effectiveness, historical manufacturing and supplier data, yields, parts analysis, and other information.

Corrective action is initiated when the QMS flags occurrences which exceed predetermined quality performance thresholds. The system was designed, programmed and integrated by BHTI personnel. Return on investment will be realized from reduced nonconformance costs. The system has experienced some bugs and implementation problems but the phased approach appears to be working well.

Phase II is planned to begin in January 1989 and will include the following features:

* Incorporation of receiving and inspection functions.
* Verifiable collection of unplanned labor.
* Real time process control.
* Direct coordinate measuring machine input.
* On-line graphics input and output.

QMS is being well received and accepted by manufacturing personnel due to extensive training and the phased implementation. It should prove to be an effective system for improving quality and controlling costs.

### *MATERIAL REVIEW BOARD CORRECTIVE ACTION*

The Material Review Board (MRB) documents the "instant" problem and gathers quality data. The corrective action process analyses the quality data and determines causes, trends and long term solutions.

Both the Material Review Chief and Corrective Action Chief report to the Manager of Product Assurance Engineering and have separate organizations to carry out their functions.

The material review process starts with an inspection report (rejection notice) provided by one of approximately 400 inspectors. The rejection is reviewed and entered into the Quality Management System (QMS) database. The rejected material is reviewed to determine its disposition. It may be used as is, scrapped, reworked, repaid or returned to the vendor.

The purpose of the corrective action process is to prevent or reduce the rate or recurrence of a defect, discrepancy, failure, or other condition judged significantly detrimental to safety, cost, quality, or performance of the product by correcting the root cause. The process is initiated by management request, document review, QMS thresholds, or analysis reports. Problems are investigated to determine the root cause and appropriate corrective action.

Problems that cannot be resolved at a lower level are resolved by Corrective Action Committees. These committees are composed of mid-level management personnel that address problems that cross departmental lines, problems unresolved by departmental corrective action activities, root causes of repetitive problems, high dollar and high frequency problems. Follow-up is assigned to ensure corrective action is effective.

## 3.3 PRODUCTION

### MANUFACTURING PROCESS INSTRUCTIONS

Manufacturing Process Instructions (MPIs) are used to amplify engineering process specifications with specific instructions for controlling individual part processing and for assuring a documented, repeatable process. MPIs are written within the limits of the associated BHTI process specification. In addition to the advantages listed above, they provide clarification of the procedures and additional process detail that eliminates interpretations on the shop floor that could result in lack of control and repeatability.

MPIs generally fall into two categories. They are either a principal procedure for general usage or a specific procedure for a specific part. Examples of principal procedures are MPIs for equipment, tools and facilities, tool preparation, material preparation and control, fabrication of kits, trimming of uncured material, thermocouples, debag and cleanup operations, and subassembly and assembly. Examples of specific procedures are MPIs for lay-up, compacting, debulking, hot drape forming, bagging for cure, and cure cycle.

MPIs also allows for changes in procedures without having to rewrite the engineering process specification. MPIs are written and controlled by manufacturing development personnel. As long as changes are below the level of detail in the manufacturing specification, they are approved and signed by only the Manufacturing Development Department, the Engineering Methods and Materials Laboratory, and the Manufacturing and Product Assurance Department.

To assure the smooth operation of the MPI practice, BHTI has established a departmental instruction for the preparation, release, maintenance and control of MPIs.

### COMPOSITE PLY MANAGEMENT

Recognizing the need for automated tracking of the increasing volume of advanced composite materials, BHTI designed and is in the process of implementing the Composite Process System (CPS). The objective of the program is to track individual plies and ensure that they are properly laid-up on the curing tools. The system provides current part and material data for process control, controls and records the fabrication and inspection processes, improves material utilization, and reduces labor.

CPS enables engineers, planners and lofters to access the engineering department's CADAM libraries to obtain part specific data such as lay-up sequence, fiber orientation, and material specifications. It is used, in coordination with Material Requirements Planning (MRP), to perform producibility studies on each part and to generate gross material requirements and material inventory checks.

CPS is tied into the shop floor operations through a bar-code wanding system. Shop workers access the system by wanding bar codes on their badges. Bar-codes placed on each ply at the cutting tables are wanded to control and verify ply lay-up and kitting. CPS also tracks the time that plys are out of cold storage and the labor spent on each part.

CPS has many values such as eliminating errors between engineering and planning, preparing individual part planning tables, releasing part work orders and tools to the shop floor, and issuing cold storage pick tickets. All manufacturing and inspection steps are logged via bar-code transactions.

### *SOFT MASTER TOOLING*

BHTI is using CATIA to access engineering part data to manufacture master tooling molds. Soft master tools are created by using the part geometry to serve as a basis for tool fabrication. Tool specific information is then added to the CATIA model to create a complete soft master tool. This soft master tool data is downloaded to a machine to fabricate the master tool, which is then used to construct bonding tools and drill and rout fixtures.

Using CATIA and NC machines to build master tools enables the reconstruction of a master tool in the event of damage without alterations to part dimensions. It also enables the creation of new master tools with minimal effort and expense in the event of engineering design changes.

### *TOTAL QUALITY MANAGEMENT*

In response to DOD TQM initiatives, BHTI is undertaking steps to develop and implement TQM at all levels of management. TQM planning and goal setting is being integrated into the company's strategic plan and training needs are being identified. Existing employee involvement mechanisms such as "Excellence Teams" program are being expanded and improved. TQM requirements are being incorporated into the Quality Management System (QMS) as they become known. Such methods as functional integration, concurrent engineering, Taguchi methods, and statistical process control are being introduced.

### *FLUOROSCOPIC INSPECTION*

A sophisticated fluoroscopic inspection system is used to detect a large number of anomalies. Among them are ply orientation, ply count, void detection, water entrapment, foreign object detection, detail fit-up, core defects, and sealant around fasteners. BHTI is currently improving its visualization and recording capability, and establishing an overall inspection approach that includes the CAT scan technique.

The effort to improve visualization and recording capability is focused on digitizing the output. With the use of a digital computer, results can be pictured graphically, noise can be reduced, and resolution can be improved.

### *DETECTION OF BACKING MATERIAL INCLUSION*

The inclusion of prepreg backing material in composite laminates is an industry wide problem. Backing inclusions are generally not detected until the material has been cured and is in final inspection. If the inclusion is large enough to cause rejection of the component, it results in a serious financial penalty.

BHTI has developed a manufacturing practice that solves this problem very effectively. Their solution is the use of an aluminum foil polyester/polyethylene backing material that is easily detectable with eddy current inspection equipment. The approach requires BHTI to replace the backing material normally supplied with prepreg broadgoods with the aluminized backing material. This material, which is designated BF-41707, is supplied by:

Bell Fibre Corporation
918 Eighth Avenue
Columbus, GA
Telephone: (404) 323-7316

The aluminized backing material can be detected through up to 20 plies of graphite/epoxy laminates. The procedure is to have the person laying up the laminate use a portable eddy current detector (such as the Hocking AV10B or NORTEC 23 models) on the lay-up before compaction. If an inclusion is found at this stage in the process, it can be easily removed. With the proper null adjustments, the detector can be used on laminates that are being layed up on aluminum, steel, graphite, and other conductive tooling materials.

BHTI conducted a thorough evaluation of the new backing material with respect to cutting, cold storage, workability and other considerations. With only minor adjustments, the aluminized backing material has been fully adopted. Since the procedure is an in-process technique, certification is not required. An additional advantage of adopting this material is that it is less expensive than currently used backing materials.

BHTI is currently informing the composites industry of this approach and is encouraging prepreg suppliers to supply prepreg materials with the aluminized backing.

## *PROGRAMMING OF COORDINATE MEASURING MACHINES*

BHTI can currently create CMM inspection programs by downloading CAD data to a diskette and putting it into the Zeiss CMM to create automated inspection programs. This improves accuracy and throughput over previous manual inspection systems.

The CMM is currently used to scan rotor blades for helicopters. In a probe pass the system will measure twist, contour, pitching moments and other engineering data. The current CMM output method is a paper report. This data is available in several formats to allow for acceptance and balancing of the part and for adjustments to the manufacturing process. The working envelope is 9300mm x 1200mm x 2000mm.

The following future enhancements are planned to further increase productivity:

* Putting a SUN workstation between the CAD and CMM systems to facilitate off-line inspection programming of the CMM.
* Using the Dimensional Measurement Interface Specification (DMIS) developed by CAM-I to permit the communication of inspection programs with other companies in BHTI teaming contracts.
* Non contact inspection using laser scanners.
* Enlarging the physical envelope.
* Capturing inspection data in an automated format for use by other ADP systems.

### *ULTRASONIC INSPECTION*

BHTI is making extensive use of ultrasonic inspection techniques for the non-destructive evaluation and testing of materials. Depending on part size and geometry, the immersion method, reflector plate method, through transmission method, and non-immersion ultrasonic inspection is used.

Immersion is used on parts having hollow centers, such as rotor blades and fiberglass spars. BHTI has the capability to inspect parts up to 18" x 36" x 25' by use of the immersion method. Parts are completely immersed in water tanks, with the ultrasonic transducer and receiver, on opposite sides of the part, able to traverse the complete distance of the part. Immersion inspection can scan at up to 15 inches per second and is able to detect small voids. It is currently used to inspect the V-22 rotor spindle.

Reflector plate inspection is similar in technique to immersion, but places the transducer and receiver on the same side of the part. A reflector plate is placed on the opposite side of the part and echoes the transducer's signal back to the receiver. This method is able to detect very small voids and porosity, ply gap, and ply misorientation. Engineering personnel inspect test panels using this method in order to optimize lay-up procedures and test standards.

BHTI uses a gantry, non-immersion or squirter method to inspect parts up to 50 feet in length, such as the V-22 upper and lower wing skins. Small voids and porosity of 5% or more are detected in panels up to 1/2 inch thick, with scanning speeds reaching 20 inches per second.

BHTI is developing hand-held, multiple transducer devices called Mobile Ultrasonic Systems (MOUS), which are used to inspect I-beam stringers. Four MOUS tools use both through transmission and pulse echo transmission to inspect four radii, the web, and four flanges of an I-beam. The MOUS tools are attached to a multiplexer, which will be connected to the gantry ultrasonic unit. Inspection data will be retrieved by an Automation Industries cell controller. Once a scan is complete, the scan data is sent to a Data General Nova 4 computer for analysis and storage on disks.

Bell is continually working on advancements in ultrasonic testing. Their efforts include enhancing pulse-echo capabilities to accurately determine flaw depth at production speeds, evaluating various transducers and frequencies to optimize part scan, and refining MOUS to enable one-pass I-beam scanning with only one MOUS tool.

## *3.4 FACILITIES*

### *TOOLING ON-LINE PROCESSING SYSTEM*

Tooling On Line Processing System (TOPS) is an on line tool accountability system that has been in use at all the Fort Worth facilities and the Amarillo and Canadian plants since 1985. The system took over two years to design and implement. It can be accessed from any terminal in the plant.

TOPS tracks tools from the planning stages through the production or purchase of the tool, maintaining a traveler history with cost data for each tool. The system tracks tools during the fabrication, repair, and rework of tools. It maintains a history of tool usage. Even tools in storage or in use by vendors are tracked. TOPS also provides on line tool orders for production with real-time response on tool allocation and issue. Tooling documents including travelers, pick tickets and shipment authorizations, are printed on line.

TOPS maintains accurate tool costs by interfacing with existing systems to accumulate hours and dollars charged for tooling. It provides accurate and timely data on the tools required to build a part. The system fully meets government inventory and reporting requirements and has been approved by the U.S. Army. Since the system has been operating, average response time from demand at the crib to delivery of the required tool at the shop has been reduced from three days to one hour.

### *CUBIC BORON NITRIDE GRINDING*

Cubic Boron Nitride (CBN) technology is used to greatly increase productivity and accuracy in grinding high precision gears. The precision requirements for these gears have led BHTI to search for methods that will allow for tight control of root radius, tooth profiles, and to use techniques that will allow for removal of a maximum of .006 inches of material from the blanks after heat treating. The CBN grinding wheels are meeting these requirements.

CBN crystals rank next to diamond in hardness and are 2 to 3 times harder than conventional grinding abrasives. The crystals normally range from 30 to 600 microns in grain size. Depending on application, they are available in two types of grinding wheels: dressable and plated. BHTI uses the plated type wheels almost exclusively even though they are considerably more expensive. Plated wheels use a hardened steel base that has been ground to the specific tooth profile and then has a single layer of CBN crystals electrolytically applied and nickel bonded. The advantages of the plated wheel include:

* More accurate form control.
* No dressing requirement.
* Less tendency to burn.
* Fastest form grinding method available.
* Consistently high accuracy.

The disadvantages include:

* Long procurement lead time.
* Limited sources (principally Kapp in Germany).
* High cost.
* Different wheel required for each tooth form.

BHTI states that the use of these wheels has provided accuracies which challenge the ability of quality assurance inspection techniques and has shown a 400% increase over conventional methods in production per shift.

## ROBOTIC GEAR HARDENING CELL

BHTI has developed and implemented a robotic gear hardening cell. The cell presently consists of a Seco/Warwick rotary hearth furnace, a Cincinnati Milacron RM-100 robot, a Gleason quencher, a degreasing machine, a Harris freezer, and a six position rotary load/unload workstation.

The heat treating process consists of the robot taking a gear blank weighing up to 100 lbs. from a load/unload station and putting it into the furnace. When the blank reaches the proper soak time at a temperature of 1650 degrees F the robot removes it from the furnace and puts it into the quench press. This process must take place within 40 seconds to maintain proper heat control. After quenching, the robot dips the blank into the degreasing tank and then places it into the freezer where it is chilled for one hour at -1600 degrees F. When that process is complete, the robot removes the blank from the freezer and returns it to the load/unload workstation.

The ability to handle blanks weighing up to 100 lbs and work in an environment of over 1700 degrees F is an ideal application of robotics. Providing consistent handling capabilities and automating a mundane labor intensive process, this cell has solved a manufacturing problem and shows good potential to improve productivity, profitability, and quality.

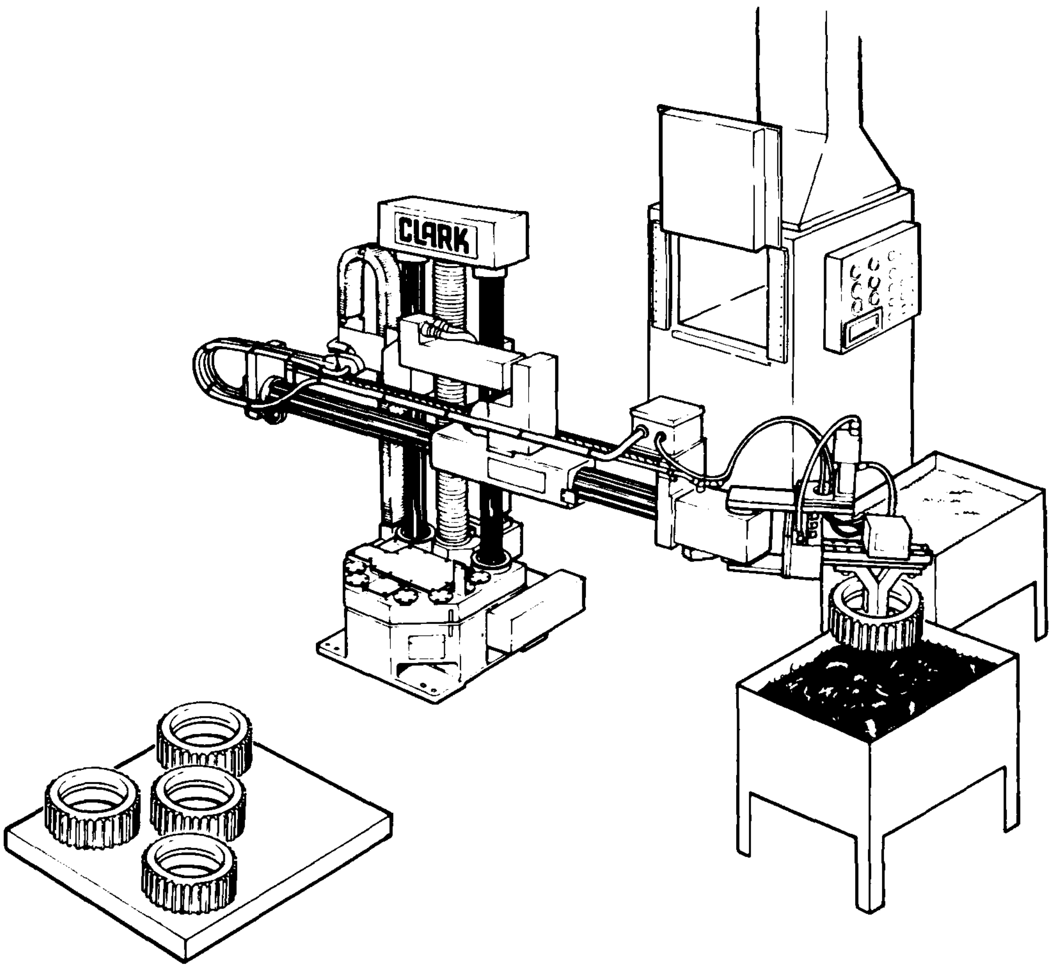


***Figure 3.4-1: Robotic Gear Hardening Cell***

## *COMPLEX CROSS-SECTION COMPOSITE FABRICATION*

BHTI has developed a manufacturing process for the fabrication and subsequent bonding of complex shaped I-beam stiffeners to the V-22 wing structure. Utilizing a combination of thermal draping and vacuum compaction, uncured stiffeners are formed which do not exhibit ply deformation, cap thinout, or web taper when cured and co-bonded to the wing planks.

Preplied stacks or charges of up to 22-plies of graphite epoxy are formed over a graphite epoxy C-channel mandrel. Forming is accomplished under vacuum once the lay-up has been heated to 150 degrees F. After the C-channels are formed they are placed back-to-back and pinned to form the basic I-beam configuration. The I-beam is subsequently compacted under vacuum at room temperature for a minimum of eight hours. During this time compaction forms the web and foot shapes to within ten percent of the final part thickness. Formed radius fillers and additional cap materials are added to the I-beam which is then subjected to another vacuum compaction cycle.

Uncured I-beam stiffeners, still incorporating the graphite epoxy C-channel mandrels, are placed on the wing skin and are cured and co-bonded to the surface under standard autoclave pressures and temperatures. Finished, cured in place stiffeners require no additional trimming or machining.

## *TOOLING FOR COMPOSITES*

BHTI is currently using state-of-the-art approaches and materials for fabricating tooling for composites. They are using plastic masters for small items such as wing and blade tips; steel for large composite tooling such as the graphite composite tooling for the V-22 wing skins; steel and aluminum for rotor blades and yokes that are NC machined; and synthetic materials and isostatic graphite that are NC machined. They are also using proprietary vendor supplied materials, such as reinforced polyurethane, that are NC machined.

BHTI is conducting in-house research to qualify new materials, and is surveying outside sources for additional materials and approaches.

The manufacturing practice followed by BHTI is that tool design is part specific. Accuracy and size constraints dictate thermal expansion considerations, and production requirements affect tool design. The fact that each tool fabrication step successively reduces final part accuracy is leading BHTI to increase implementation of CATIA modeling and NC machining of tools. BHTI is also trying to improve current non-CATIA methods and the development and selection of new materials.

### *CLOSED CAVITY TOOLING FOR COMPOSITES*

BHTI is using closed cavity tooling for curing composite primary rotor system components, and for fabricating main rotor system yokes. This process guarantees repeatability, assures control of finished dimensions, and reduces secondary machining operations.

To assure the success of this approach, BHTI has established several manufacturing practices. The most critical of these are the accurate sizing of prepreg details, the tandem use of mechanical pressure and vacuum pressure techniques at ambient and higher temperature conditions during lay-up in order to optimize compaction, and the strict control of resin content and fiber areal weight.

Sizing of details is accomplished by using accurately controlled belt winding of prepreg roving and precision cutting of details from broadgood prepreg with chisel cutters fitted to a computer controlled Gerber cutting machine. Compaction (debulking) is performed during the fabrication of the V-22 yoke, for example, by the two methods listed above. Ambient tempe turc nd mechanically induced compaction are accomplished with customized, pres d rubber bladders.

The flexibility of this approach allows compaction at various stages during the lay-up in the curing tool at pressures up to 40 psi. Heat compaction using vacuum is performed in the curing tool at 130 - 140 degrees F for two hours. It is applied twice during lay-up. This procedure progressively controls bulk factor and resin bleedout. The strict control of resin content and fiber areal weight is accomplished by the kitting of details of known resin and fiber content. This balancing approach compensates for the variation in resin and fiber content of prepreg material as it is received from the supplier.

Another lay-up technique is also used that allows for thermal expansion differences of the yoke lay-up and the steel tooling during final cure. This technique consists of the use of spring loaded side walls at selected locations on the tool.

## *COMPOSITE ROTOR BLADE FABRICATION*

Composite main rotor blade fabrication at BHTI varies with blade model, but all of the blades are final cured in closed cavity metal tooling. Although many of the main rotor blade manufacturing techniques used at BHTI are used throughout the industry, BHTI has developed and uses several unique manufacturing practices.

One practice is the use of prepreg roving for the winding of spar straps. This assures final blade balance and weight, and eliminates resin squeezeout during winding around hinge pins. Prepreg roving stock is analyzed when it is received from the supplier for resin and fiber content. In the winding step, rolls of prepreg roving are selected that together will yield the desired resin and fiber content in the final blade.

Another practice is the use of a styrofoam mandrel covered with a rubber bladder for final curing of main rotor blade spars. In this approach, molded styrofoam segments are fitted onto a stiff inner support rod, and are then covered with a rubber bladder. The bladder is pressurized during the cure process in order to provide internal pressure. The mandrel is easily removed from the cured spar due to the thermal contraction of the styrofoam during the cure.

Several other practices that assure success in blade manufacture are presented in the preceding description of closed cavity tooling for composite fabrication.

## *MACHINING AND DRILLING OF COMPOSITE STRUCTURES*

BHTI has issued an internally generated set of documents for use in the machining and drilling of composite structures. Descriptions of acceptable tools, cutters and practices are provided along with the definition of processing limits and expected results if these limits are exceeded.

Carbide drill and cutter designs were generated by BHTI. These emphasize maximum air passage clearance for residue removal and cooling, along with positive advanced cutting angles to ensure minimum contact time between the cutting surface and the composite detail. Carbide drills provide average linear cuts of thirteen inches or approximately 200 holes before refinishing is required.

Cutting tools and processes covered by these documents include not only basic composite structures but hybrid structures of various composite metal combinations. Tool control for manual operations is achieved by either direct feed control or higher pressure check.

### *AUTOMATED TAPE LAYING*

BHTI is advancing automated composite fabrication through the development and implementation of automated tape laying for the lower wing skin of the V-22 aircraft. BHTI uses a 10-axis Ingersoll tape laying machine (TLM) which has up to a +30 degree laydown angle capable of laying 3", 3-1/2" and 6" unidirectional tape at a rate of up to 1200 inches per minute. The TLM has an operating envelope of 50' x 12' x 4'.

Natural Path Programming (NPP) is used to determine ply location and orientation of each ply layer. NPP also adjusts for excessive gaps and butts. Once part programming is complete, part programming data is converted to machine code and sent to an Allen Bradley 8200 cell controller which synchronizes machine movements.

Tape is layed directly on the part tool. Tape backing paper is used to carry the tape to the laydown head, and is then retrieved on a take-up reel. Two three-inch diameter rotary carbide cutters enable one to three separate cuts at either end of a ply prior to laydown. The cutters have a minimum cutting angle of four degrees from the center line. Zero-degree cuts are possible in order to slit the tape. The cutting depth is critical, and must be adjusted for tape thickness and temperature.

The tape laying head compacts each ply at laydown through the use of twelve 1/2" wide segmented rollers which are controlled independently. Compaction pressure is adjustable from 170 to 370 psi.

The benefits of this system include lap and gap control, improved repeatability and accuracy, improved quality, reduced material waste, and reduced direct labor associated with the laydown process.

BHTI has enhancements planned for the TLM to extend the machine's current capabilities. These include increasing the lay-up rate with a new controller which would reduce head turn-around time after each ply is layed, providing tool surface digitizing, providing look-ahead look-behind foreign object detection, and improving the tape cutter and tape guidance system.

### *FILAMENT WINDING*

BHTI has successfully modified and adapted commercial filament winding systems to produce its family of complex rotor system components.

Filament winding techniques and processes have been developed for use in the fabrication of complex, highly loaded structural rotor system elements. Filament winding systems from Ingersoll, McClean Anderson and Goldsworthy Engineering are being utilized to produce rotor blade spars and highly loaded straps for yoke assemblies. In addition, filament winding is being used to produce conversion spindles and proprotor grips for the V-22 aircraft.

Polar winding is utilized to wind major tension load straps for lug attachments in yokes, proprotor grips and end fittings of rotor blades. In the case of rotor blades the thick straps for lug attachments are transitioned and shaped to form the spar shell, which is usually a relatively thin walled D-spar. Numerous ply packs and localized filler pad build-ups are also produced by polar wrapping of prepreg tow materials. Unique to the polar winding process utilized by BHTI is the ability to transition and shape the unidirectional tows during winding in the x, y, and z directions through the use of innovative tooling and compaction aids.

More conventional methods of filament winding are used to produce other parts such as the conversion spindle, proprotor grips and control tubes. The winding approaches used are standard within the industry, but part specific steps dependent on subsequent part processing methodology. Several parts produced by filament winding are cured in closed female tooling. To eliminate part shrinkage and fiber movement during cure, each torsional or helical wrapped ply is slit longitudinally prior to cure. This allows outward part growth against the female tool during cure while maintaining proper fiber alignment.

## *COMPUTERIZED DOT PEEN MARKING MACHINE*

The computerized dot peen marking machine provides BHTI with a consistent means of legibly marking a wide variety of material. It is not dependent on the individual skills of the person marking the part.

The Marktronic machine is built by the Wetzel Tool Company of Bloomfield, Connecticut. The system is a computer controlled machine tool capable of marking a line of text, straight or circular, with up to 24 characters. It consists of an IBM PC with a minimum 256K RAM, a controller, and a marking head. Text is entered via the keyboard and a wide variety of sizes and depths are available. Each character is formed by a series of dots that are arranged in a 5" x 7" matrix. The characters are indented by means of a carbide tipped stylus driven by a solenoid actuated punch. Editing of all text is accomplished by adding, inserting, or deleting characters without having to retype the whole line prior to marking the part.

The text layout can consist of one to eight lines. The system has the ability to store up to 1,440 layouts in six groups of up to 240. Back-ups of all layouts may be made and stored for future use.

## *THEODOLITE APPLICATIONS*

BHTI is utilizing computer assisted theodolites to accurately measure difficult surface geometry. The TOMCAT 2000 coordinate analyzing theodolite system is a portable measuring system. Two or more systems can be used to measure complex geometries with a single setup. The system is menu driven and provides step-by-step instructions to guide the operator through each operation. Target data can be manually entered from the system keyboard or downloaded from a CAD file. The system is capable of storing eight different coordinate systems at the same time to allow the operator to set coordinate systems for aircraft, tool, part, etc. and switch between them as required.

The system includes an analysis module to allow the operator to evaluate geometry and compare data files. The operator can also combine files if necessary to gain more detailed information about the part or tool. BHTI has used the system to reverse engineer existing parts and build a CAD file for final design definition. The system has proven to be accurate and quick and has provided a significant reduction in time required for tool and part verification.

BHTI intends to expand the usage of the theodolite system for periodic inspection of tools and gauges, assistance in part assembly, verification of complex contours, and eventually for gaugeless tooling.

### *WIRE HARNESS AUTOMATED MANUFACTURING SYSTEM*

BHTI began development of an automated wire harness manufacturing system during the mid 1970s. Wire Harness Automated Manufacturing System (WHAMS) was initially implemented in 1981. Major benefits resulting from the implementation of WHAMS include:

* Reduced wire waste.
* Reduced use of identification sleeves.
* Reduced duplicate layout boards.
* Reduced rework effort.

These benefits translate into a $2.1 million first year cost reduction resulting from a $750 thousand implementation cost. Use of the system has resulted in an 80% reduction in labor in the wire cut and stamp area and a 40% reduction in labor in the harness layout area.

The principal concept behind WHAMS is to use a manufacturing data base to provide electronic data for automated and manual operations in the wire harness manufacturing process. Currently, data developed by various electrical engineering and planning activities are resident on a BHTI mainframe computer as part of the BEIMS system. These data are downloaded into a local manufacturing computer to create a WHAMS database. This data is used to group like cable types so that continuous filament wires can be processed through the manufacturing cell.

WHAMS data is used to drive an automated wire marking system capable of placing identification markings every 2-1/2 inches at speeds up to 350 feet per minute. The system uses an AB Dick Videojet Printer and an American Can model IJM Wire Transporter. After marking, the wires are spooled and heated to cure the ink markings.

Harness layout boards are set-up and marked into zones for wire end termination to assist in the proper routing of wires. The layout process uses data from WHAMS but remains a manual operation. Wire routing is accomplished manually with the assistance of computer displayed instructions. Wire sleeve identification tags are automatically printed out. Harnesses are cut and bundled, wires are stripped and crimped, and end terminations are made up manually using WHAMS generated printouts.

Future automation plans include elimination of the printouts and expanded use of WHAMS data.

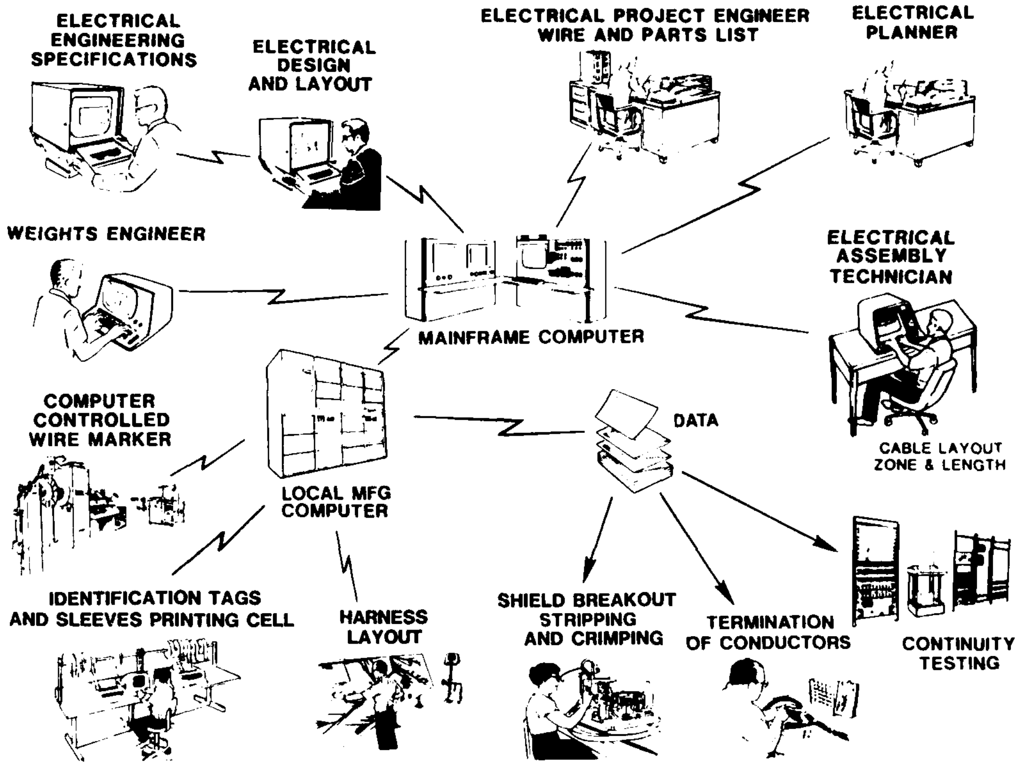


***Figure 3.4-2: Wire Harness Automated Manufacturing System***

## *CNC SPIRAL BEVEL GEAR GRINDER*

BHTI and Gleason Gear Works are currently in the process of jointly developing and implementing a CNC gear grinder for spiral bevel gear manufacturing.

Working jointly under an Army funded MM&T project since 1986 the two companies are developing a CNC grinding machine that will manufacture spiral bevel gears faster, with more consistency, and with less operator dependency.

Starting with an existing manual machine, the two companies have designed a machine with an improved CNC controller. The machine has the following features:

* DC drives for the cradle generating cam and the work spindle.
* A variable speed grinding wheel spindle.
* An electronic feed controlled work spindle with a magnetic particle brake for positive positioning.
* A new wheel dresser arrangement with two-axes CNC contouring capabilities and a variable speed rotary diamond dresser.
* Digital read-outs are provided on selected non-controlled axes, thus eliminating the use of the vernier scale and providing consistent positioning data to all operators.

The machine was re-built and tested at Gleason and then delivered to BHTI and installed in Plant 5 in August 1988. It is currently going through its final Phase III testing.

Early tests by BHTI indicate some significant savings in the manufacturing process. A typical run of 25 parts on the current machines requires 74 hours total manufacturing time. The same parts manufactured on the CNC grinder require only 22.5 hours.

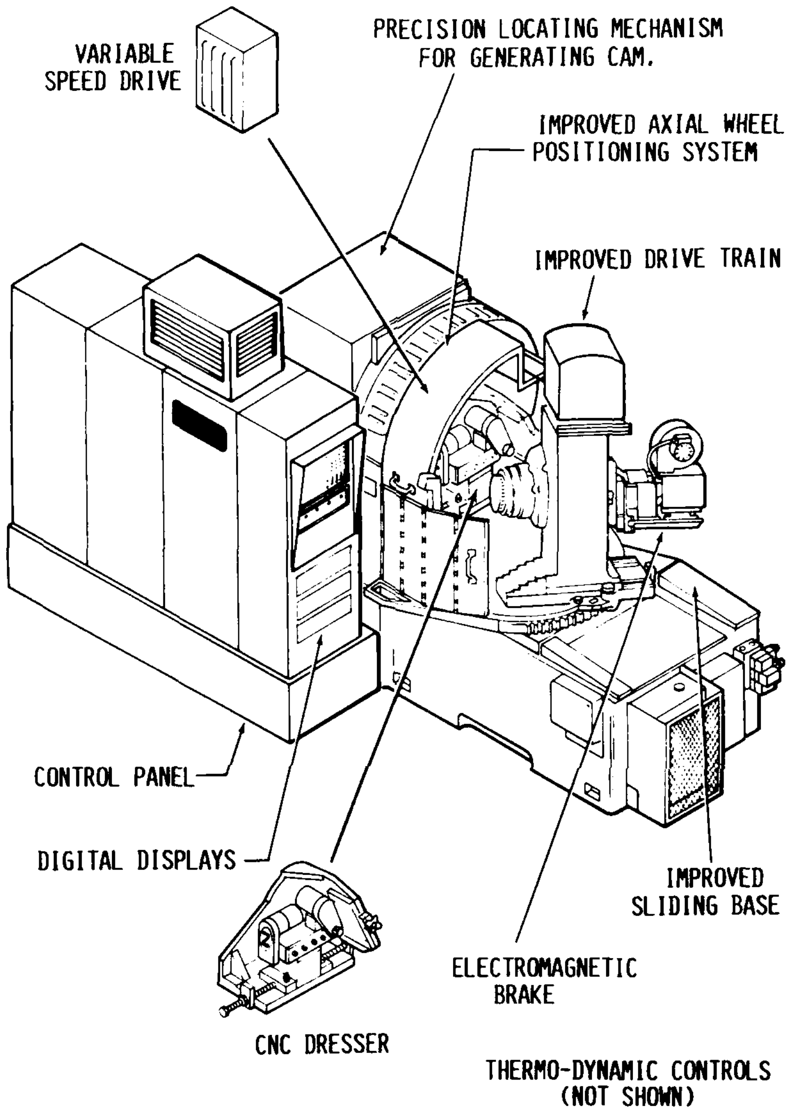


***Figure 3.4-3: Modified Gleason Gear Grinding Machine***

## *3.5 LOGISTICS*

### *INTEGRATED LOGISTICS SUPPORT*

BHTI has developed and maintains a comprehensive worldwide customer support organization which accounts for approximately 31% of their business. Customer support is one of BHTI's top priorities and often is the deciding factor in a customer's decision to buy a Bell product. BHTI has a goal of 24 hour turnaround time for shipment of repair parts for a commercial aircraft which needs a part to be able to fly.

## 3.6 MANAGEMENT

### EXCELLENCE TEAMS

BHTI has a very well implemented and successful quality circle program called "Excellence Teams". The teams are groups of 4 to 12 people from the same work area or who do similar work. They meet on a regular basis to identify, analyze, and solve problems in their work area. The team concept stresses employee involvement and cooperation. It combines the strengths of group dynamics and a systematic problem solving approach.

The Excellence Teams are supported by a steering committee, facilitators, team leaders, and coordinators. Team leaders and members train together in a 24 hour training program. There are currently 28 teams formed and over 300 people trained. Ten team projects have been completed. Early reports indicate an approximately 3 to 1 ratio of the benefits realized to program cost. The teams have improved communication, morale, and efficiency. A completed team project at one facility is projected to reduce material handling losses by $500K. At another facility an excellence team reduced scrap from 11% to zero.

There have been some problems caused by membership changes on teams, interference from routine work assignments, lack of a broad understanding of the effort within the company, and availability of resources. But these problems are being overcome. Plans call for expansion to 60 teams by the end of 1989 with increased publicity and an expanded recognition program. BHTI believes the key to the success of this program is steady, controlled growth.

### TRAINING

BHTI has developed a comprehensive training program that supports all facets of their operation from initial design to customer support. BHTI training personnel are highly qualified and motivated people who believe that they are an essential part of their company's success. High teacher to student ratios are part of their training philosophy.

The courses offered serve the needs of the employees as well as the company by providing skills that aid in job promotion as well as job performance. BHTI has developed specific courses which meet customer needs and also junior college courses which provide a benefit to the community at large.

The training course materials (notebooks, training aids, etc.) are produced in-house and are of professional quality. Course content is developed in conjunction with the organizations within the company that need the training.

## 3.7 TRANSITION PLAN

### STRATEGIC MANUFACTURING PLAN

BHTI has developed a dynamic long range strategic planning process for transitioning from design to manufacturing. This process was initiated in response to a V-22 contractual requirement and has developed significant top level interest and support.

BHTI has produced a strategic manufacturing plan that:

* Maximizes manufacturing throughput and minimizes inventory.
* Maximizes resource (equipment, personnel, and material) utilization.
* Ensures that manufacturing processes and equipment will be available for production.
* Provides estimates on equipment, tooling, layout, and manpower required for various rates of production.
* Defines software requirements for manufacturing.
* Drives funding for manufacturing research and development.
* Examines, researches, and develops new manufacturing technologies prior to actual need.

This plan was produced by a diversified team representing all facets of the manufacturing process.

One of the tools used to develop the strategic manufacturing plan is simulation. It has "fleshed out" the transition plan and provides the necessary detail to determine requirements for capital investment. The simulation process used by BHTI emulates the actual characteristics of a system and predicts how the system will operate. They can identify such things as resource requirements, throughput, bottlenecks, layout design, system coordination, storage requirements, as well as other important factors.

The major benefit of this planning process to BHTI has been the ability to preplan the total V-22 facility and manufacturing process, including the ramp-up to full production.

# SECTION 4

# PROBLEM AREAS

## *4.1 PRODUCTION*

### *SHIMMING OF COMPOSITE STRUCTURES*

Shimming for and during assembly of composite structures is a continuing industry-wide problem experienced by BHTI during the assembly of the V-22 wing. Approximately 17% of the wing assembly time was associated with various aspects of the shimming operation: machining of preplanned, cured in-place hard glass and carbon epoxy shims; feeler gauge measurement of gaps between details; application of laminated shims; and placement and curing of castable shims. The shimming operation is extremely labor intensive and must be accomplished within very exacting limits. All gaps above 0.008 inch must be shimmed. Castable shims cannot be used above 0.030 inch. Laminated shims are used for gaps greater than 0.030 inch. The type of shim used is dependent on the material of the two interfacing surfaces.

The solution is to reduce the large percentage of assembly effort devoted to shimming operations. The need exists to develop improved shim materials for broader applications. These would primarily be castable materials. Test programs need to be conducted to define the allowable limits for the various shimming methods. The sources for gap build-up in part details need to be defined in order that tooling, processes and material specifications can be modified as required to reduce part mismatch.

# APPENDIX A

## TABLE OF ACRONYMS

| Acronym | Definition |
|---|---|
| ADP | Automated Data Processing |
| AFTCS | Automatic Fatigue Test Control System |
| AMRF | Automated Manufacturing Research Facility |
| BEIMS | Bell Engineering Information Management System |
| BHTI | Bell Helicopter Textron, Inc. |
| BMP | Best Manufacturing Practices |
| CAD | Computer Aided Design |
| CADAM | Computer-Graphics Augmented Design and Manufacturing |
| CAT | Computer Aided Tomography |
| CATIA | Computer Aided Three-Dimensional Interface Applications |
| CBN | Cubic Boron Nitride |
| CMM | Coordinate Measurement Machine |
| CNC | Computer Numerically Controlled |
| CPS | Composite Process System |
| DMIS | Dimensional Measurement Interface Specification |
| DOD | Department of Defense |
| EMPF | Electronics Manufacturing Productivity Facility |
| MDR | Material Discrepancy Reports |
| MM&T | Manufacturing Methods and Technology |
| MOUS | Mobile Ultrasonic Systems |
| MPI | Manufacturing Process Instructions |
| MRB | Material Review Board |
| MTI | Metalworking Technology Incorporated |
| NC | Numerically Controlled |
| NDI | Nondestructive Inspection |
| NPP | Natural Path Programming |
| PC | Personal Computer |
| QMS | Quality Management System |
| TLM | Tape Laying Machine |
| TOPS | Tooling On-Line Processing System |
| TQM | Total Quality Management |
| WHAMS | Wire Harness Automated Manufacturing System |

# APPENDIX B

## BMP REVIEW TEAM

| Team Member | Agency | Role |
|---|---|---|
| Leo Plonsky<br>(215) 897-6686 | Naval Industrial Resources Support Activity<br>Philadelphia, PA | Team Chairman |
| CDR Richard Purcell<br>(202) 692-3422 | Office of the Assistant Secretary of the Navy (S&L) (RM&QA-PI)<br>Washington, DC | Team Leader<br>Management |
| CDR Douglas Tidball<br>(202) 692-0815 | Office of the Assistant Secretary of the Navy (S&L) (SPECAG)<br>Washington, DC | |
| Robert Jenkins<br>(301) 227-1363 | David Taylor Research Center<br>Bethesda, MD | Team Leader<br>Metals<br>Production |
| Jack Tamargo<br>(707) 646-2137 | Mare Island Naval Shipyard<br>Vallejo, CA | |
| John Lallande<br>(301) 286-6208 | NASA/Goddard Space Flight Center<br>Greenbelt, MD | |
| Ferrel Anderson<br>(309) 782-6226 | U.S. Army Industrial Engineering Activity<br>Rock Island, IL | Team Leader<br>Composites<br>Production |
| Richard Celin<br>(201) 323-2173 | Naval Air Engineering Center<br>Lakehurst, NJ | |
| Robert Neff<br>(513) 255-7277 | Air Force Wright Aeronautical Laboratories<br>Dayton, OH | |
| Ed Turissini<br>(317) 353-7965 | Naval Avionics Center<br>Annapolis,MD | Team Leader<br>Design |
| James Mays<br>(202) 697-4561 | Naval Supply Systems Command<br>Washington, DC | |
| Steve Thoman<br>(215) 441-7273 | Naval Air Development Center<br>Warminster, PA | |

# 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:

Office of the Assistant Secretary of the Navy
(Shipbuilding and Logistics)
Directorate for Reliability, Maintainability, and Quality Assurance
Production Assessment Division
Attn: Mr. Ernie Renner
Director, Best Manufacturing Practices
Washington, DC 20360-5100
Telephone (202) 692-0121

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

COMPANIES SURVEYED

Litton Systems, Inc.
Guidance & Control Systems Div.
Woodland Hills, CA

Honeywell, Inc.
Underseas Systems Division
Hopkins, MN

Texas Instruments
Defense Sys & Electronics Group
Lewisville, TX

General Dynamics
Pomona Division
Pomona, CA

Harris Corporation
Government Support Systems Div.
Syosset, NY

IBM Corporation
Federal Systems Division
Owego, NY

Rockwell International Corp.
Collins Defense Communications
Cedar Rapids, IA

UNISYS
Computer Systems Division
St Paul, MN

Motorola
Government Electronics Group
Scottsdale, AZ

General Dynamics
Fort Worth Division
Fort Worth, TX

Texas Instruments
Defense Systems & Electronics Group
Dallas, TX

Hughes Aircraft Co.
Missile Systems Group
Tucson, AZ

Control Data Corporation
Government Systems Group
Minneapolis, MN

Hughes Aircraft Company
Radar Systems Group
Los Angeles, CA

ITT
Avionics Division
Clifton, NJ