REPORT OF SURVEY CONDUCTED AT

NASA MARSHALL SPACE FLIGHT CENTER

HUNTSVILLE, ALABAMA

JANUARY 1993

Best Manufacturing Practices

OFFICE OF THE ASSISTANT SECRETARY OF THE NAVY
(RESEARCH, DEVELOPMENT AND ACQUISITION)

PRODUCT INTEGRITY DIRECTORATE
“CRITICAL PATH TEMPLATES
FOR
TRANSITION FROM DEVELOPMENT TO PRODUCTION”
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SECTION 1
EXECUTIVE SUMMARY

1.1 BACKGROUND

The Navy’s Best Manufacturing Practices (BMP) program team conducted a survey at the NASA Marshall Space Flight Center (MSFC) located in Huntsville, Alabama the week of 11-15 January 1993. The purpose of the MSFC survey was to review and document its best practices and investigate any potential industry-wide problems. The BMP program will use this documentation as an initial step in a voluntary technology sharing process among the industry and government.

1.2 BEST PRACTICES

The best practices documented at MSFC are detailed in this report. These topics include:

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<tr>
<td>Implementation Requirements Planning</td>
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<tr>
<td>MSFC’s Mission Operations Laboratory has defined a Requirements Acquisition Process to collect and understand user requirements for the design and development process.</td>
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<tr>
<td>NASA Unified Standard for Factors of Safety and Verification</td>
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<tr>
<td>NASA Centers have developed basic requirements for a standard establishing uniform structural strength requirements for factors of safety and verification.</td>
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<td>Specification and Data Requirement</td>
<td>8</td>
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<tr>
<td>An MSFC advisory committee addressed the need to improve specifications and data requirements in procuring systems from contractors.</td>
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<tr>
<td>Engineering Flow Dynamics: Adjusting to Market Dynamics</td>
<td>8</td>
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<tr>
<td>The Aerophysics Division at MSFC has created a new market for the study of internal systems by applying experience in fluid dynamics.</td>
<td></td>
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<tr>
<td>Solid Propulsion Integrity Program</td>
<td>9</td>
</tr>
<tr>
<td>The Solid Propulsion Integrity Program is establishing an engineering foundation and database for improvements in the success rate of domestically-produced solid rocket motors.</td>
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<tr>
<td>Hardware Simulation</td>
<td>9</td>
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<tr>
<td>MSFC has developed simulation facilities to test, design, and identify system improvements, to test methodologies, and to assist in personnel training.</td>
<td></td>
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<tr>
<td>Optical System Design, Fabrication, Test and Design</td>
<td>10</td>
</tr>
<tr>
<td>The Optical Systems Branch has developed capabilities in its mission to perform research and development in optical systems design, fabrication, and test and analysis.</td>
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<tr>
<td>Audio Emulation Facility</td>
<td>10</td>
</tr>
<tr>
<td>The Computer and Data Systems Division has established an audio facility to evaluate audio communication systems for the space shuttle.</td>
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<tr>
<td>Environmental Control and Life Support Systems</td>
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<tr>
<td>MSFC has a test facility to develop and refine processes and systems for environmental control and life support technologies.</td>
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<td>Telemetry Processing Systems</td>
<td>11</td>
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<tr>
<td>MSFC has developed Telemetry Format Standards to reduce the cost of telemetry communications to and from orbiting space vehicles.</td>
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<tr>
<td>SSME Test Bed</td>
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</tr>
<tr>
<td>The Propulsion Laboratory has a technology test bed for testing new development concepts and techniques and has implemented a technology integration process to ensure its success.</td>
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Failure Investigation Process
MSFC’s failure investigative process demonstrates the Center’s commitment to correcting subsystem failures.

Optical Plume Anomaly Detector
The Optical Plume Anomaly Detector detects anomalous situations in investigations involving high temperatures.

Engineering Photographic Analysis
The Engineering Photographic Analysis laboratory has developed a system for analysis of photographic images of space shuttle launches and rocket engine tests.

Automatic Data Analysis and Anomaly Resolution
The Propulsion Laboratory has an automatic data analysis system to quickly analyze large amounts of data and highlight any problems in a space shuttle main engine test firing.

Neutral Buoyancy Simulator Facility
The Neutral Buoyancy Simulator simulates the weightlessness of space for crew training and procedure development.

Automated Fiber Placement Composite Manufacturing
MSFC is automating the manufacture of complex composite shapes as a means of controlling mechanical properties.

Cryogenic Insulation
MSFC has developed a material formulation and process for applying cryogenic insulation on the external fuel tanks of space launch vehicles.

Intelligent Processing Systems - Arc Welding Systems
The Metals Processing Branch has developed capabilities as NASA’s only welding research and development organization.

Intelligent Processing Systems - Ablator Applications
The Center has developed a robotically applied, low density sprayable ablator.

Intelligent Processing Systems - Hydroblast Refurbishment
MSFC developed an automated, transportable water blast system that can be programmed to follow robotic motion paths to remove the thermal protection systems from miscellaneous locations on the solid rocket boosters.

Optically Stimulated Electron Emission for Surface Cleanliness Inspection
Optically Stimulated Electron Emission inspection techniques have replaced visual inspection at MSFC to scan for the presence of contaminants in the solid rocket motor case.

Integrated NDE Data Evaluation and Reduction System Program
MSFC developed a system to provide diagnostic capabilities and quantitative NDE to verify solid rocket motor designs and production units.

Kinematic Simulation of Robotic Processes
The MSFC Productivity Enhancement Complex workcells use articulated arm robots and air bearing turntables on hardware to perform operations such as spraying.

Laboratory Portable Spectroreflectometer
The Materials and Processes Laboratory at MSFC is using a handheld instrument to measure reflectance of large surfaces in the field.

X-ray Calibration Facility
The X-ray Calibration Facility at MSFC is a high vacuum test chamber designed for the calibration of X-ray instruments.

Productivity Enhancement Complex
The Productivity Enhancement Complex is a complex of research cells operated cooperatively by teams comprised of NASA, industry and university personnel.

Simulations for Procedure Verification Training
MSFC extensively uses simulation to verify mission equipment and procedures as well as training mission personnel.
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<tr>
<td>Training Assessment Team Process</td>
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<tr>
<td>A Training Assessment Team has been assembled early in the mission planning cycle to improve planning for training.</td>
<td></td>
</tr>
<tr>
<td>Integrated Facility Operations</td>
<td>22</td>
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<tr>
<td>To accommodate increases in mission support functions for multi-purpose activities, MSFC is implementing a re-engineering effort to streamline processes and service functionalities.</td>
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<tr>
<td>Payload Activity Scheduling</td>
<td>22</td>
</tr>
<tr>
<td>The Experiment Scheduling Program is used to schedule all experimental activities during an orbiter science mission.</td>
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<tr>
<td>Procurement Innovations</td>
<td>23</td>
</tr>
<tr>
<td>The continuous improvement philosophy at MSFC is manifested in the Procurement Office where over 25 specific actions are in process to eliminate identified impediments and foster improvements throughout the acquisition process.</td>
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<tr>
<td>Product Development Teams</td>
<td>23</td>
</tr>
<tr>
<td>MSFC developed the concept and guidelines for using Product Development Teams in the concurrent development of a specific product.</td>
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<tr>
<td>Technology Transfer</td>
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</tr>
<tr>
<td>The MSFC Office of Technology Utilization pursues an aggressive technology transfer program aimed at the transfer of NASA derived technologies to state and local government, American industry, and academia.</td>
<td></td>
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<tr>
<td>Equipment Inventory Process</td>
<td>24</td>
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<tr>
<td>MSFC has identified and implemented an inventory-by-grid-location method that has improved the efficiency and effectiveness of its physical inventory process.</td>
<td></td>
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<tr>
<td>Spacelab and Payloads Council for Excellence</td>
<td>25</td>
</tr>
<tr>
<td>The Spacelab and Payloads Council for Excellence is a NASA/contractor team responsible for overall management of the TQM and continuous improvement activities.</td>
<td></td>
</tr>
<tr>
<td>MSFC/Contractor Quality and Productivity Partnership</td>
<td>25</td>
</tr>
<tr>
<td>The Partnership acts as a catalyst for continuous improvement among MSFC, its contractors, and subcontractors.</td>
<td></td>
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<tr>
<td>Customer Support Services</td>
<td>26</td>
</tr>
<tr>
<td>The NASA Program Support Communications Network was implemented in 1984 and is serviced by MSFC and Boeing Computer Support Services and is highly successful because of the excellent partnership that exists between MSFC and Boeing.</td>
<td></td>
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<tr>
<td>Technical Penetration of Projects</td>
<td>26</td>
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<tr>
<td>The MSFC employs a number of techniques to maintain a high degree of technical involvement in outside-contracted projects.</td>
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### 1.3 INFORMATION

The following information items are detailed in this report.

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<td>The Structural Design Division’s Management is meeting the challenge of a young and growing skill level engineering work force.</td>
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<tr>
<td>Control System Prototyping</td>
<td>27</td>
</tr>
<tr>
<td>Control Systems Prototyping isolates an experiment platform from the rest of the orbiting platform using a combination of hardware that is controlled with motion detecting devices and software.</td>
<td></td>
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<tr>
<td>Hypervelocity Impact Facility</td>
<td>27</td>
</tr>
<tr>
<td>The Hypervelocity Impact Facility at MSFC is used to determine the effects of micrometeoroid and space debris collisions with various space hardware.</td>
<td></td>
</tr>
<tr>
<td>Flight Software Development Processes at MSFC</td>
<td>28</td>
</tr>
<tr>
<td>The software processes used to design and develop success-critical systems at MSFC have reached a high level of perfection.</td>
<td></td>
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</tbody>
</table>
Configuration Management
The MSFC configuration management staff has developed several policy and procedural handbooks governing the initial program requirements and design modification process with contractors providing system hardware to programs.

Test Program Control and Change Process
A configuration control process has been established in the MSFC Propulsion Laboratory to provide uniform procedures for managing rocket engine tests.

Battery Failure Analysis and Life Prediction
The Astrionics Laboratory at MSFC is investigating the possibility of using frequency response techniques for enhancing destructive physical analysis of battery failures and non-destructive testing of batteries.

Electrical Power System Development
MSFC has developed simulated environmental testing to demonstrate high voltage power processing unit reliability.

Hydrogen Test Facility
The Hydrogen Test Facility can be used to evaluate the mechanical properties of materials in the environments encountered in hydrogen propulsion systems.

Database Information Systems
MSFC developed three extremely integrated databases for use by the aerospace industry.

New Ways of Doing Business
The MSFC Engineering Cost Group performed a cost quantification study called New Ways of Doing Business to find out why it costs so much to do business and to recommend ways to do it better, cheaper, and faster.

Continuous Improvement
Continuous improvement efforts and TQM at NASA are guided by the NASA Quality Steering Team which is composed of senior managers and chaired by the NASA Administrator.

1.4 PROBLEM AREAS
The BMP Survey Team documented the following problem areas:

Interdisciplinary Analysis Improvements
Common data that must be shared by all the analytical software tools and current existing software cannot be easily transported to other software systems.

Chlorofluorocarbons and Solvent Replacement
Although MSFC has taken the offense in finding substitutes for ozone depleting materials in all of its processes, it has a shared problem with industry in that drop-in replacements do not exist for all applications and the time line to find acceptable replacements is short.
SECTION 2

INTRODUCTION

2.1 SCOPE

The purpose of the Best Manufacturing Practices (BMP) survey conducted at the NASA Marshall Space Flight Center (MSFC) in Huntsville, Alabama was 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 and government facilities. The ultimate goal of the BMP program is to strengthen the U.S. industrial base and reduce the cost of defense systems by solving manufacturing problems and improving quality and reliability.

A team of engineers accepted an invitation from MSFC to review the processes and techniques used in its facilities located in Huntsville, Alabama. Potential industry-wide problems were also reviewed and documented. The review was conducted at MSFC on 11-15 January 1993 by the team identified in Appendix B of this report.

The results of BMP surveys are entered into a database for dissemination through a central computer network. The actual exchange of detailed data will be between companies at their discretion.

The results of this survey should not be used to rate MSFC with other government activities, defense contractors, or commercial companies. The survey results have no bearing on one facility’s performance over another’s. "The documentation in BMP reports is not intended to be all inclusive of the activity’s best practices. Only selected non-pro-prietary 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 MSFC’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.” MSFC identified potential best practices and industry-wide problems. These practices and other areas of interest were discussed, reviewed, and documented for distribution 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 at MSFC reviewing practices, processes, and equipment. In-depth discussions were conducted to better understand and document the identified practices and problems.

Demonstrated industry-wide problems identified during the Best Manufacturing Practices surveys may be referred to one of the Navy Manufacturing Technology Centers of Excellence. They are identified in Appendix C.

2.3 ACTIVITY OVERVIEW

The Marshall Space Flight Center was established in 1960 and is a field installation of NASA. MSFC is recognized as a national leader in propulsion systems; payload design, development and integration; and science investigations. Its extensive areas of expertise include management of complex programs; systems engineering and integration; systems development; payload systems analysis and integration; the technical disciplines encompassing propulsion systems, structural systems, material science and engineering, electronics, guidance, navigation and control, power systems, data systems, environmental control and life support systems; optical systems; and science and applications areas of astrophysics, earth science and applications, low gravity science, and solar terrestrial physics.

With 3,700 employees occupying over 1,800 acres in the U.S. Army Redstone Arsenal in Huntsville, Alabama, MSFC also includes facilities in the Michoud Assembly Facility in New Orleans, Louisiana, the Yellow Creek Production Facility in Mississippi, the Slidell Computer Complex at Slidell, Louisiana, and the John C. Stennis Space Center in Mississippi. MSFC facilities include structural and test-firing facilities for large space systems, and specialized laboratories for studies and facilities for assembling and testing large space hardware.

MSFC’s specific capabilities include:

- Scientific and engineering activities associated with design, development, test, mission operations and evaluation of space launch vehicle transportation systems and payloads.
- Planning and conceptual development of new programs in support of MSFC and NASA objectives.
• Technical services and program support activities including facilities planning, construction and maintenance, purchasing, contract administration, technology utilization, computer operations, and communications support.

Current projects include the Space Shuttle, Advanced Solid Rocket Motor, Space Station Freedom (in conjunction with the European Space Agency, the Canadian Space Agency, and the National Space Development Agency of Japan), the Hubble Space Telescope, Advanced X-ray Astrophysics Facility (AXAF) development, the Inertial Upper Stage and Transfer Orbit Stage vehicles, and the Tethered Satellite System.

2.4 ACKNOWLEDGMENTS

Special thanks are due to all the people at MSFC whose participation made this survey possible. In particular, the BMP program acknowledges the special efforts of Mr. Larry Lechner and Mr. Leonard Howell, for enabling this survey to occur.

2.5 ACTIVITY POINT OF CONTACT

The information included in this report is descriptive of the best practices and techniques observed at NASA; however, it is not all inclusive. The reader will require more detailed data for technology transfer. This data is available through the survey point of contact.

The point of contact for this BMP survey is:

Mr. Larry Lechner
Continuous Improvement Office
Marshall Space Flight Center
Mail Code C003
Bldg. 4200
Huntsville, AL 35812
(205) 544-5227
FAX: (205) 544-2610
SECTION 3
BEST PRACTICES

NASA's Marshall Space Flight Center (MSFC) is the first non-Department of Defense government facility at which the Best Manufacturing Practices program has conducted a survey. NASA and its Centers have long been advocates of technology transfer with a deep commitment that goes beyond legislatively dictated efforts. This commitment is strongly manifested in MSFC's exemplary relationship with its contractors. At no other facility or company surveyed by the BMP program has the relationship between government and contractor been stronger and more mutually beneficial than at this NASA Center. Not only does this relationship enhance the technology and expertise transfer between NASA and contractor, but also among contractors. This environment, coupled with a strong positive attitude among personnel, contributes to a teamwork atmosphere where employees are open to new ideas and projects are pursued with excellence through continuous improvement.

MSFC is like many government installations in that it is undergoing a period of re-evaluation and re-adjustment of its activities and services. It maintains a vision of becoming the world's leader in space transportation systems and therefore, TQM initiatives are becoming more critical at the Center. A grass roots TQM effort has already begun, is influencing many aspects of project work, and is gaining momentum among management with impressive results.

The guiding principle towards achieving MSFC's goals of excellence and continuous improvement are supported by a strong dedication to learning new ways of doing things and sharing that technology and expertise with industry and other government activities. These interrelated beliefs were most apparent in the excellent presentations given to the survey team. The BMP Survey Team considered the following practices to be among the best in industry and government.

3.1 DESIGN

DESIGN REQUIREMENTS

Implementation Requirements Planning

The Mission Operations Laboratory at MSFC has defined a Requirements Acquisition Process to collect and understand user requirements for the design and development process. MSFC previously experienced difficulties in obtaining timely, clearly stated user requirements for engineered systems. These problems resulted from the failure of users to understand the types of requirements needed by implementors to define system functions; the inability by implementors to clearly explain to users the types of requirements needed to define system functions; and user concepts evolving with the design, resulting in continual changes to the system.

The Requirements Acquisition Process provides general descriptions and detailed procedures to develop tools needed to establish good lines of communication between implementor and user. In 1991, a team from MSFC addressed this problem using Quality Function Deployment (QFD). The goal was to determine an efficient means of obtaining and evaluating requirements from users. The team identified 10 characteristics of a quality Requirements Acquisition Process using the QFD methodology.

After analyzing the 10 characteristics defined from QFD, MSFC determined that the development of an Implementor's Requirements Guide (IRG) should be the initial step in the development of an efficient process for obtaining and evaluating requirements. This guide provides instructions and techniques in the development and design of any system within the Mission Operation Lab. The IRG is currently under development and will be published and institutionalized in March 1993. An automated expert systems version of the IRG will be operational approximately 18 months after document publication.

MSFC is anticipating several benefits from implementing the IRG including the timely acquisition of user requirements; user requirements that accurately reflect the user's need; clearly understood user requirements; and fewer engineering changes late in the design process.

NASA Unified Standard for Factors of Safety and Verification

After determining that requirements for structural strength design and test verification vary at the different NASA Centers, a working group of representatives from all Centers has developed basic general requirements for an agency-wide standard establishing uniform structural strength requirements for factors of safety and verification. After a formal review, the new uniform standard will be implemented through a workshop for both government and industry. This standardization will improve inter-agency
Centers and government/contractor interpretation issues, as well as providing useful design guidance to the Structural Engineering community.

In addition to the unified standard on factors of safety, other technical topics directly related to structural design have been recommended for unification, providing additional benefits to both the agency and its contractors.

**DESIGN PROCESS**

**Specification and Data Requirement Tailoring**

MSFC management established an advisory committee of management and technical personnel to address the need to improve specifications and data requirements (DR) in procuring systems from contractors. While working with contractors, the committee determined that there were many problems associated with the specifications and DRs. For example, specifications were found to be too restrictive with too many “how to’s” that discouraged innovation, and standard DRs did not provide the right data. Redundant and unnecessary data was being collected across the program, some data was found to be not cost effective, and the overall data requirements were insufficient for program management in some cases.

The advisory committee recommended that specifications and DRs be tailored for system procurement rather than relying on standard or boilerplate documents. This recommendation, supported by management, led to a pilot program with MSFC selecting existing specifications and DRs to be tailored for this program. A team approach was used, and government and contractor interests were included in the development of the new documents.

As a result of MSFC efforts, streamlined new specifications and DRs were produced, and a total of 17 pages of specifications replaced the previous 75 pages. No “how to’s” were included, allowing the contractor to use innovative approaches. Two DRs were also produced that better capture real data requirements. The specifications and DRs have not yet been used for procurement because of program curtailment for which these were developed.

MSFC maintains that it expects benefits from the use of improved specifications and DRs to include shorter procurement cycle times, lower cost for contractors in system development, and appropriate data reporting.

**Engineering Flow Dynamics:**

**Adjusting to Market Dynamics**

With the completion of the space shuttle design in the early 1980s, the Aerophysics Division at MSFC faced a reduced work load. However, the Division found that it could apply the fluid dynamics experience used in aerospace vehicle design to study other internal systems such as liquid propulsion systems and solid rocket motors, and in so doing, create a new market niche.

The Division tailored personnel and facilities to serve this new market. MSFC chartered and worked with a consortium of fluid dynamics experts for space applications to avoid producing redundant facilities at the Center. This consortium included representatives from the DoD, research organizations, other NASA facilities, industry, universities, and small businesses.

The Division then developed a propulsion system computational fluid dynamics and cold flow test capability. This combined capability is unique to NASA and provides a new way of performing propulsion system design. Using this facility and the expert personnel knowledge developed with it, the Aerophysics Division has been able to bring in new NASA sponsored work as well as new private industry customers.

The Aerophysics Division has been participating in a teaming relationship with the consortium for about three years and has derived many benefits from the relationship (Figure 3-1). The Division has been able to accelerate capabilities develop-
ment by capitalizing on the previous work performed by consortium members rather than new development. Also, the teaming relationship allows the Division to have a peer review of ideas and concepts before committing resources. The consortium has been a critical key to the successful transition of the Division into this new market.

DESIGN ANALYSIS

Solid Propulsion Integrity Program

The MSFC Solid Propulsion Integrity Program (SPIP) effort is establishing an engineering foundation and database for improvements in the success rate of domestically-produced solid rocket motors (SRMs). The SPIP was initiated in 1986 to address weak areas in SRM—specifically, nozzles, bondlines, and propellant and insulation. This effort has several critical goals including:

- Developing engineering tools such as analytical modeling techniques, processing techniques, and effective NDE methods
- Effecting a cultural change with a commitment to excellence
- Developing a scientifically based (not empirically based) industry
- Improving specifications and the use of hands-on experience for young engineers to become “smart” buyers.

Several areas addressed include standardized test methods for propellants; development of constitutive equations to describe the propellant under load; expert witness panels for recording actual rocket motor processing conditions; and development of a high temperature (1200 degrees F) fiber optic strain sensor. A Conical Bond-In-Tension test specimen has been developed and accepted as a JANNAF research tool. This test specimen allows a common database to be established to compare bondline strength data and to disposition anomalous flight hardware. One-dimensional, coupled thermal/pyrolysis gas flow computer codes have been developed and released to the SRM industry which—for the first time—discretely model the effect of pore pressure on nozzle ablative material failures. A Nozzle Aero Thermochemistry code was also developed and provided to industry with the capability to calculate two-dimensional and three-dimensional flow fields and the resulting heating conditions. This code yielded a 20 percent improvement in computed boundary conditions used to generate margin of safety predictions.

The SPIP is improving the solid rocket motor engineering base and industry culture. It is providing communication channels and technical information among SRM manufacturers, suppliers, and government. Extensive use of hands-on experience is being used to train smart government buyers of SRMs. NASA, through MSFC and a commitment to excellence, has been established as a leader in the SRM industry.

Hardware Simulation

MSFC has developed simulation facilities to test, design, and identify system improvements; test methodologies; and assist personnel training. Major components tested at this facility include the engine controller and the hydraulic actuators. Flight operations can be simulated including testing of redundant features, and actual flight sensor data can be replayed by the laboratory controllers.

The Orbital Docking Simulation Laboratory simulates orbiting vehicles during rendezvous and docking studies as well as contact dynamics for docking and berthing mechanism evaluation. The facility contains a hydraulically driven and computer-controlled, six degrees of freedom motion simulator. Control stations allow test subjects to fly a simulated vehicle using displays and control of orbiting vehicle systems including control sticks similar to those planned for orbiting vehicle control. Mathematical models are developed and computerized to represent flight vehicles under analysis and development, and force and moment sensors provide dynamic feedback during closed loop control. Visual simulation is available through an advanced graphics system.

Test hardware weights up to 20,000 pounds can be attached and accelerated to ±0.6 g’s. Lighter payloads can be accelerated to ±3 g’s. Position travel is ±4 feet and a tilt of ±30 degrees. The laboratory can be used for programs other than docking and berthing studies. The Navy recently used the test bed to study the effects of surface effect ship movement on sailors where ship motion was simulated while sailors rode the platform.

The Space Shuttle Main Engine (SSME) Hardware Simulation Laboratory (HSL) facility tests and verifies the SSME avionics and software system using a maximum complement of flight-type hardware. The HSL permits evaluation and analysis of SSME avionics hardware, software, control systems, and mathematical models. It is also a test bed for integrating hardware, software and hydraulics, and is unique in its authenticity, complexity, and scope of simulation. The HSL is an invaluable tool in the design and development of the SSME firing, enabling problem isolation and resolution prior to the event.

MSFC also has a Robotics Laboratory for simulation of remotely managed systems such as a free-flying space craft.
Automatic Rendezvous and Docking technology is developed and tested. The facility occupies 17,890 sq. ft. within building 4619 and includes a 4,000 sq. ft. precision epoxy floor with a 6 Degree of Freedom (DOF) free-flying mobility vehicle. An overhead crane with a 6 DOF robotic arm can carry a payload of up to 1,000 lbs. and move within the volume of the facility. Orbital lighting simulation is also available.

The Robotic Laboratory also contains developmental hardware to support on-orbit servicing, manipulator system development and capture of tumbling satellites.

Optical System Design, Fabrication, Test and Analysis

The MSFC Optical Systems Branch has developed impressive capabilities in support of its mission to perform research and development in optical systems design, fabrication, test and analysis, and to provide technical support to center projects in these areas. Projects undertaken by the branch include the Advanced X-ray Astrophysics Facility-I, Advanced X-ray Astrophysics Facility-S, Laser Atmospheric Wind Sounder, and Space Laser Energy.

The Optics Branch, covering over 14,700 square feet of laboratory space, houses several facilities including Binary Optics, Coating Facility, Optical Design and Analysis, Optical Fabrication, Optical Metrology Facility, Optical Test Tower, and a Precision Optical Fabrication laboratory which has a Moore Special Test M-40 diamond turning machine. Supported technologies include ladar technology for acquisition rendezvous and docking; CO₂ laser transmitter development; optical technology for mechanical/thermal/optical modeling; ion polishing; plasma-assisted chemical etch; X-ray optical system design; binary optics; and optical quality polishing of high mach number wind tunnel nozzles which requires polishing a surface nozzle of five inches to one inch contraction to a precision of a few microns.

The highly sophisticated Optical Systems Branch also accommodates the unique stray light test facility. This stray light capability, which is singular throughout NASA and industry, is a patented measurement technique used to test high performance, high fidelity models. The measurement system utilizes a 100 meter long experimental optics vacuum chamber Bi-Directional Reflectance Distribution Function (BRDF) measurement equipment developed to characterize the scatter properties of coatings and mirror surfaces. These technologies and the measurement equipment are now entering the third generation of development. Current capabilities allow extremely high stray light reflection ratios of $10^{15}$ or greater to be measured. In the near future, $10^{-7}$ torr vacuum will be achievable. A new BRDF measurement allows measurements at visible, ultraviolet, and infrared wavelengths.

Audio Emulation Facility

An audio facility has been established in the Computer and Data Management Division at MSFC to evaluate voice communication links for Space Station Freedom. This facility is also used to develop and evaluate caution and warning alarms for the space station. The audio facility is comprised of a sound isolation chamber and various studio quality equipment for sound production such as audio signal generators, digital audio tape recorders, compact disk players, amplifiers, studio quality speakers, programmable graphic equalizers, and audio analyzers.

The audio facility can be used to determine the expected performance quality of communications links from the technical specifications. The system can also be used to modify voice recordings such as clip signals to mimic their transmission over specific vendor equipment and add background noise. This emulation of communications can help evaluate the expected performance of a system during the design phase before the equipment is built. Tests performed in the laboratory include analysis of analog and digital processing algorithms; simulation of the effects of channel degradation; analysis of contractor provided data; and the development of advanced concepts such as voice synthesis.

Currently, work is focused on the evaluation of audio caution and warning alarms aboard the space station. One objective is to establish consistent sound characteristics for alarms implemented by different system vendors. Another objective is to evaluate the effectiveness of multiple, concurrently sounding alarms. The facility has demonstrated that current audio specifications could be interpreted differently by different vendors. This work has led to development of clearer technical specifications and algorithms for describing alarm signals.

3.2 TEST

INTEGRATED TEST

Environmental Control and Life Support Systems

The Manned Habitat Environmental Control and Life Support Systems Test Facility supports MSFC’s mission to develop and refine necessary processes and systems for environmental control and life support (ECLS) technologies. Originally formed to directly support the Space
reduce the cost of long distance-digital data communication.

Inclusion within the ECLS facility are working simulation modules for wastewater collection and purification, atmospheric control and air recovery systems which control the oxygen pressures and levels, carbon dioxide removal/reduction systems, and smoke/fire detection systems. Individual ECLS subsystems have been integrated into a full scale habitat simulator measuring 15 feet in diameter and 40 feet long that is capable of operating at ambient and reduced pressures. This habitat simulator provides a self-enclosed ecosystem for testing and evaluation of the numerous environmental control systems required for life support.

The unique partnering agreements between MSFC and its Life Support Subsystem contractors has facilitated one of the most advanced systems development and integration laboratories in the world. NASA relies on its Life Support Systems contractors – such as Boeing and United Technologies/Hamilton Standard – to provide the necessary environmental control systems. However, new and improved designs, and concepts and process theories continually evolve to refine, modify, and improve existing technologies.

Experienced on-site contractors, co-working with MSFC personnel, provide an environment that facilitates personnel involvement through teamwork instead of working in a more traditional government/contractor relationship. This relationship provides the advantages of shared or free flowing information between parties while improving morale. Systems engineers and designers have used the facility to gain first hand, working knowledge of processes and integration issues. This effort allows them to return to the designing environment with enhanced knowledge of system requirements.

This unique partnering has allowed MSFC personnel to gain invaluable knowledge into ECLS technologies and integration issues leading to advanced shipboard ECLS systems in a short time, and this knowledge will then be applied to the procurement process. Consequently, MSFC can ensure the procurement of what is needed with no time or money lost by reordering needed ECLS systems.

Telemetry Processing Systems

MSFC has developed Telemetry Format Standards to reduce the cost of long distance-digital data communication – or telemetry – to and from orbiting space vehicles for payload experimentation. This effort minimizes cost impacts for ground processing software required to accommodate new downlink telemetry structures that would result if no standards were in place.

MSFC has been assigned mission responsibility for numerous payloads for a variety of space programs. Each payload typically consists of multiple experiments that are executed while in orbit. Consequently, data must be interactively exchanged between ground support personnel located in the Huntsville Operation Support Center (HOSC) and the payload crew to properly execute the experiment and capture the experimental data.

All flight systems have different telemetry construction concepts which lead to a potential for ground processing software to constantly be in flux due to the introduction of new telemetry construction techniques. Each occurrence of a sample must be databased, resulting in extremely large databases that are not conducive to real-time telemetry processing.

During the design phase of these flight software systems, the issue of data transmission format becomes critical. Without proper standardization, a costly customized downlink telemetry structure must be procured. MSFC resolved this problem by implementing a set of rules – the Telemetry Format Standard – for data formats, not only saving money, but also providing for easier database descriptions of telemetry sample arrangement and precluding the requirement to database each sample occurrence.

Results of MSFC’s efforts have been demonstrated on multiple orbital missions including the Spacelab, Space Transportation System/ Shuttle, Inertial Upper Stage, Hubble Space Telescope, and Tethered Satellite System. With the Telemetry Format Standard developed prior to the design of these various spacecraft, minimal cost impacts were absorbed by the HOSC ground processing facility.

A future effort of MSFC’s Telemetry Processing Systems group will be the conversion from Time Division Multiplex Telemetry Format Standards to the International Consultative Committee in Space Data Systems recommendation of Packet Telemetry. MSFC has donated its experience with standard formats to help in the adoption of these new standards.

DESIGN LIMIT

SSME Test Bed

The MSFC Propulsion Laboratory has a technology test bed for testing new development concepts and advanced technologies under actual engine operating test conditions.
For example, the Space Shuttle Main Engine (SSME) test facility (Figure 3-2) has a test capability of 7.5 million pounds with a foundation designed to 12 million pounds. It can accommodate up to 75,000 gallons of liquid hydrogen fuel and 23,000 gallons of liquid oxygen.

The SSME test bed has a substantial data collection capability. The bed can be instrumented by 750 channels of digital and 108 channels of analog information, and all channels can be active simultaneously. The data collected on SSME testing has improved the characterization of SSME operation, enhanced the SSME database, and increased understanding of the hot fire environment. These improvements in turn result in improved anomaly resolution, models, and designs, as well as enhanced calibration of sub-scale testing.

To ensure the test bed’s success, MSFC implemented a Technology Integration Process (TIP). This process includes an up-front evaluation of integration requirements/issues/costs and the assignment of an Integration Engineer (IE) to facilitate smooth integration of the new test item into an existing test bed. The IE has extensive knowledge of the test hardware and how the new test item affects the test bed. This TIP can be applied to other high technology test beds.

**TEST, ANALYZE, AND FIX**

Failure Investigation Process

MSFC’s commitment to discovering and correcting the causes of subsystem – or component – failures is evidenced in its failure investigation process. This investigative process encompasses four areas:

- Isolation and identification of the failed component
- Search of the pedigree or similar types of failures of similar components
- Review of test activity with similar components
- Investigation of the human handling of the component for possible failures due to human error.

FIGURE 3-2. SSME TEST BED
Before removing the failed component, all failure data is assembled and reviewed. In some cases, additional diagnostics are run to verify the exact failure, and a unique investigative plan is developed for the specific component including reviews of the component life history. Detailed records are maintained on serialized items that show use of all components on other systems, for tests, and any other use. This process provides information on repair or rebuild history, expected wear out, time in service, and stresses that may have been applied prior to the current test. Manufacturing records are reviewed for discrepancies or waivers that might have been accepted during the component manufacturing process.

The pedigree investigation includes an operational and historical review for similar failures, and a development/qualification program for the component is reviewed for design weaknesses that could indicate marginal capability. A design review is initiated, and a fault tree is constructed. The failure is analyzed using standard approaches which are dependent on failure type. Possibilities of human error may be examined including reviewing all procedures, installation, and checkout associated with the component. An investigation is conducted to determine if proper procedures had been implemented. In addition, all touch activity not related to the component is investigated, including removals to service other components, or work in proximity to the failed component.

FIELD FEEDBACK

Optical Plume Anomaly Detector

MSFC’s Optical Plume Anomaly Detector (OPAD) system detects anomalous situations in scientific and technical investigations involving high temperatures such as combustion. This method was developed to monitor rocket engine health by studying the existence of anomalous material such as material extraneous to the liquid fuel used in the rocket engine, in the exhaust plume of the rocket engine.

OPAD is conducted by optically examining the rocket plume for elements external to the rocket fuel and includes the spectroscopic analysis of the rocket plume. Because every chemical element has an identifiable spectrum, a high spectral resolution wide band-pass spectrometer was developed using diode arrays and fiber optics. Codes are being developed to allow automated quantification of material in the plume.

A typical output (Figure 3-3) from an engine test indicates significant evidence of metallic species, primarily Cr,
Fe, Mn, and Ni, throughout the test, suggesting component wear. At MSFC, this technique has helped in solving several problems. It was used to examine pre-burner face-plate erosion on the Technology Test Bed Engine, and to track bearing cage condition. This technique—which could have applications in the aircraft engine industry—is also being used for quantification of anomalous material and for verification of plume codes.

**Engineering Photographic Analysis**

MSFC’s Engineering Photographic Analysis laboratory has developed a state-of-the-art system for the analysis of photographic images of space shuttle launches and rocket engine tests. Functions of this photographic analysis system include anomaly and problem detection, motion analysis, image enhancement, view reconstruction, and view prediction (Figure 3-4). The laboratory produces a report after each space shuttle launch that details findings based on the analysis of films.

The laboratory has constructed a sophisticated integrated system from a wide array of film, video, and computer graphics hardware and software. Examples of the systems which have been integrated include film motion analyzers, microscopic film viewers, color image digitizers, image enhancement software, image measurement and analysis software, computer-aided design system, video mixers, and color output devices. The system is capable of handling a variety of film and video formats. Using the system, technicians can overlay wire frame CAD drawings of systems on digitized film images. This capability is very useful for establishing a reference frame in fuzzy images.

The system has provided many benefits because of the unique capability for reconstructing the events surrounding a space shuttle launch. A number of motion film cameras capture each space shuttle launch from key vantage points with films sent to MSFC for analysis. Deflection of the tip of the space shuttle during the initial moments of launch is also measured. Films are checked frame by frame for anomalies such as movement of debris around the shuttle during launch. Engineers study key frames to account for each anomaly and initiate corrective action in the redesign of space shuttle systems where required.

**Automatic Data Analysis and Anomaly Resolution**

The MSFC Propulsion Laboratory has set up an automatic data analysis system that was designed to quickly analyze a large amount of data and to pinpoint any problems (anomalies) that might have occurred in SSME test firing. The data to be analyzed is obtained from over 250 sensors over a period of a 500 second test firing. The automatic computerized data reduction system is capable of reducing data process time considerably, thereby increasing the productivity of the engineers. Prior to the implementation of the system, it would require eight hours after the test to obtain a hard copy of the data graphs, and require a minimum of five minutes to review several graphs for comparison. With the new system, graphs can be obtained on a computer terminal within a few minutes while several graphs can be compared with historical data in a few seconds.

The system has an expert system which reviews the data to determine if any problems have occurred in the system during the test firing. The expert system looks for anomalies by comparing present test data with historic data. A major module of the new system is in its final stages of validation. This Data Reduction and Anomaly Resolution System will have industry-wide data reduction testing applications for aircraft engines and gas turbines.
3.3 PRODUCTION
QUALIFY MANUFACTURING PROCESS

Neutral Buoyancy Simulator Facility

MSFC's Neutral Buoyancy Simulator (NBS) Facility (Figure 3-5) simulates the weightlessness of space for crew training and procedure development for space missions. This water tank measures 40 feet deep and is 75 feet in diameter, making it the largest of the two such government owned facilities. The capabilities of the NBS ensure that simulations conducted at the facility provide a realistic experience for customers. The NBS is large enough to handle a full-size mock-up of the space shuttle's cargo compartment and other full-size space hardware.

Actual space suits are used for tests at the NBS. A variety of space suit components are stocked and can be assembled to create a suit to accommodate most sizes. Maintenance and repair of these space suits is normally performed in-house, thereby reducing the cost of providing suits for tests and alleviating downtime for repairs.

Volunteer divers support tests conducted in the facility. Divers maintain other full time positions at MSFC but are also certified SCUBA divers. This practice of using volunteer divers allows MSFC to provide the simulation services at a lower cost to its customers. Because divers are used on an as-needed basis, the NBS facility does not support them during periods when no testing is being conducted. Twenty-five full-time divers would be required and only used a portion of the time. Divers also benefit from this practice. They gain hands-on experience with space hardware, and experience a change from their daily routines. Divers often work harder to maintain their normal work load so they can be free to dive when needed.

The test operation normally follows a specified approach. The customer provides detailed information to plan the test and then acts as test director during the test. MSFC then writes dive procedures including safety requirements, rehearses the procedures in the dive tank, and then conducts...
the actual task assignment. After completion of the assigned task, a complete debriefing is held with all participants including the customer, divers, safety personnel, mission specialists, astronauts, and engineers. Audio and video tapes of the actual task execution are made and analyzed by all concerned personnel.

Using this specific approach allows the MSFC to determine how long a specific task will take in space; verify the feasibility of accomplishing the desired task; establish written and proven procedures for completion of the task; and check out of the actual equipment prior to implementation of the procedure.

Automated Fiber Placement Composite Manufacturing

MSFC is automating the manufacture of complex composite shapes as a means of controlling mechanical properties. Various mechanical properties of composite structures such as tensile strength and coefficient of thermal expansion depend heavily on the orientation and positioning of composite fiber or tape material. Composite materials are used to fabricate structures that are lighter and stronger than structures constructed of metals. Through control of the base composite material and the fabrication process, the structure’s physical characteristics can be adjusted to the desired values. Commonly used manual lay-up processes are often not sufficiently precise nor repeatable to obtain the desired mechanical properties for composite components.

MSFC automates the composite lay-up process for highly complex geometric shapes. Fiber placement machines are robotically controlled and have the capability to vary the number of fibers (on the fly) to precisely place material onto complex surfaces. The ability to drop and add fibers can maintain part boundaries and uniform part thicknesses by eliminating overlap or increasing thickness where the design dictates. This effort saves valuable material and eliminates manual insertion of material. An MSFC automated fiber placement machine also mechanically presses the fibers onto the surface to eliminate entrapped air and inner band gaps. This uniform compaction reduces debulking requirements, processes concave and asymmetrical surfaces, and supports a fiber steering capability.

By using this automated process instead of a manual lay-up process to form complex composite shapes, MSFC can provide greatly improved control of composite properties which depend on fiber orientation and positioning. Automation of the lay-up process has also reduced waste of composite fiber material by eliminating unwanted overlap and cut off scrap.

Cryogenic Insulation

MSFC has developed the materials formulation and process for applying cryogenic insulation on the external fuel tanks of space launch vehicles. The insulation must provide a totally sealed aluminum/insulation interface, and prevent cryogenic pumping, prevent break-up during flight, and maintain these properties until the required fragmentation at the proper re-entry point of the fuel tanks.

MSFC is currently using CFC-11 as a blowing agent for the foam formulation. A second generation blowing agent of HCFC-141b, coupled with compatible insulation delivery equipment, has been developed and is undergoing qualification testing. A third generation agent is also under development and may reduce insulation weight while maintaining the required insulating characteristics. While this may be compatible with existing delivery equipment, new insulation delivery equipment may be required.

The process developed at MSFC uses a multi-nozzle, recirculating spray head coupled with robotics manipulation and a variable output pumping system to apply the insulation. This process allows a controlled application of the insulation to ensure insulation thickness and density. At a recent EPA conference, it was reported that MSFC was approximately two years ahead of the foam application industry in CFC replacement.

Intelligent Processing Systems - Arc Welding Systems

The MSFC Metals Processing Branch is the principal welding research and development organization in the agency. An ultimate goal of this branch is to improve weld productivity through automation and process controls leading toward higher quality welds and reduced rework. MSFC has developed capabilities including variable polarity plasma arc welding; robotic welding; welding control and sensor development; low pressure/vacuum plasma spray; and space welding.

The variable polarity plasma arc welding process developed at MSFC utilizes reverse current cycles that provide cathodic cleaning. The process reduces the number of weld passes, eliminates cleaning steps and effects a 90 percent reduction in the number of weld defects. Most major aerospace contractors now use the process, and it is baselined for virtually all mechanized aluminum welding on large space structures.

MSFC has developed the capability and processes to perform vacuum arc welding in space, and space shuttle experiments are being proposed to prove out the processes and equipment. Robotic welding for the SSME was first demonstrated at MSFC and implemented between 1987 and
1991, MSFC now has world-class welding systems supporting SSME as well as other MSFC programs. Controls and sensors for mechanized welding processes have been developed at MSFC beyond existing commercial capability. Computer graphics simulation programs for off-line programming of the robots eliminates production delays due to robot path programming and allows optimized manufacturing cell layouts without the need for actual hardware. A database of welding and material information is being developed to improve weld process development and minimize duplication of efforts.

Intelligent Processing Systems - Ablator Applications

MSFC has developed a robotically applied, low density sprayable ablator that is applied 1/8-inch to 1/2-inch thick to the space shuttle solid rocket booster (SRB) and then cured with heat. Ablative coatings are required on external surfaces of SRBs to provide thermal protection. Prior to the development of a sprayable ablative material and application process, this protection was provided by hand bonding sheets of cork composition material to external surfaces of the SRB.

The Marshall Sprayable Ablator-2 (MSA-2) in use today was first flown in March 1989 and not only provided the required thermal protection but greatly improved the flight performance of the SRB. Figure 3-6 shows the divoting – or separation of ablative materials – area reduction achieved with this formulation instead of the MSA-1 formulation. Another formulation under development at MSFC, MSA-3, is an environmentally friendly, water based formulation that will replace the MSA-2 solvents methylene chloride and perchloroethylene.

The application process consists of a programmable logic controller, pump, mixer, valves, spray gun, robotic manipulator, turntable, and a data logger for recording critical process control parameters. Programming of the system is accomplished off line through the use of computer simulation graphics. This simulation allows the geometry of the hardware that will be ablative coated to be integrated into the computer-controlled spray program and selected process control parameters of the equipment to be established prior to receipt of the actual hardware.

Intelligent Processing Systems - Hydroblast Refurbishment

MSFC has developed an automated, transportable water blast system that can be preprogrammed to follow robotic motion paths to remove the thermal protection systems (TPS) from miscellaneous locations to facilitate disassembly of the space shuttle solid rocket boosters. SRBs are covered at critical locations with the TPS to shield the base metal against the intense drag and heat generated by high velocity during launch. These SRBs are retrieved and refurbished after each launch. Prior to the development of a new system, the removal of this protection system was
accomplished by manually hydroblasting the specified areas using a hand held water jet operating at 15,000 psi.

The robotic programming is accomplished through computer graphic simulation without physical mock-up. The graphic simulation allows the engineer to determine blast areas, blast paths, angles of attack, and nozzle stand-off distance, relative to the flight hardware. The employment of sensors and software interrupt routines automatically safeguard personnel and hardware from unacceptable conditions such as improper deck leveling, and height and water pressure beyond acceptable ranges.

Through the use of the robotic waterblasting system and computer graphic simulation preprogramming, TPS removal time has been reduced by 40 percent, operator fatigue factors and operator safety concerns are eliminated.

**PIECE PART CONTROL**

Optically Stimulated Electron Emission for Surface Cleanliness Inspection

MSFC has complemented visual inspections with Optically Stimulated Electron Emission (OSEE) inspection techniques in contamination scanning (Conscan) of the Space Shuttle Solid Rocket Motor (SRM) case. The OSEE is a non-destructive, automated inspection method for detecting surface contaminants on almost 100 percent of the case surface. The SRM case is grit blasted and then covered with Conoco HD2 grease for corrosion protection during storage and shipment. Before use, the case interior must be insulated with nitrile butadiene rubber for protection during propellant burn. The grease degrades the rubber’s mechanical properties and reduces the bond strength between the rubber and the case. To ensure a sound bond, all grease must be removed. The cases are currently cleaned by vapor degreasing with trichloroethane.

Inspection of the case for surface contaminants was previously conducted visually. However, visual inspection was considered subjective and low levels of contaminants difficult to detect. Black lights were frequently used to aid in detecting organic contaminants, but this required additional handling to place the case in a dark area. The Materials and Processes Laboratory applied OSEE to the SRM case inspection. The OSEE uses a mercury vapor bulb to supply ultra-violet energy. This energy strikes the sample surface causing electrons to be released. Electrons are detected by a collector in the OSEE sensor. Surface cleanliness can be determined by measuring the amount of electrons emitted by the sample surface. This technique can measure contamination levels of less than one milligram per square foot. The contaminants encountered in this application include silicones, oils, and greases.

The OSEE method can inspect the SRM case, which is 12 feet in diameter and 20 feet long, in 30 minutes. OSEE allows real time quantitative surface mapping and also allows the data to be archived for future reference and Statistical Process Control (SPC). The OSEE can also be coupled with other surface inspection techniques such as infrared to provide a valuable surface inspection tool. The OSEE can be easily modified to quickly examine large areas or small areas with a great deal of precision.

The application of OSEE inspection techniques to the SRM case provided several benefits to the shuttle program. The OSEE is an automated system that provides quantitative data of surface contamination. It removes inspector subjectivity and provides repeatable contamination measurements. These quantitative values can be used in quality control or SPC. This inspection method is inexpensive and can be used for surface cleanliness testing of a variety of metal parts.

**Integrated NDE Data Evaluation and Reduction System Program**

MSFC developed an Integrated NDE Data Evaluation and Reduction System (INDERS) to provide diagnostic capabilities and quantitative NDE to verify SRM designs and production units. NDE methods can be valuable tools for evaluating the quality of SRM assemblies and components. Historically, NDE data is of a qualitative nature, making it difficult to be used for pass/fail decisions which would be better based on quantitative data. Specific problems encountered with NDE included data collection techniques and coordinate systems that were not standardized or repeatable, no well-defined methodology for correlating NDE data to destructive test data, and no methodology for predicting nozzle performance based on as-measured material properties.

The INDERS program effort provided a methodology to develop quantitative acceptance criteria for critical components, particularly rocket motor nozzles. Data values for NDE tests such as computed tomography (CT), ultrasonic testing (UT), and eddy-current testing (ET), are mapped to a part-based coordinate system. This consistent coordinate system allows direct comparisons of NDE results from test to test, as well as a correlation between different types of NDE testing – such as CT and UT – on the same part location. Following the establishment of part locations which include the extremes of the NDE test results, quantitative NDE properties are obtained. Then destructive mechanical tests are performed on interesting part locations, and results are correlated to the NDE data. This correlated data allows NDE methods to be used to evaluate production unit data without destructive test sampling plans.
MSFC plans to expand the capabilities of INDERS to perform finite element modeling on NDE image data, and to trace and eliminate root manufacturing causes of defects. The INDERS program has developed a methodology to correlate NDE test results to destructive test data. As a result of the NDE data being more quantifiable, the Advanced Solid Rocket Motor program has accepted ultrasonic and real-time radiography techniques over conventional film radiography techniques. The overall efficiency and quality of both NDE and materials test data analysis have been dramatically improved.

**Kinematic Simulation of Robotic Processes**

A number of workcells at the MSFC Productivity Enhancement Complex (PEC) use articulated arm robots and air bearing turntables to perform various operations such as spraying on space shuttle hardware. The PEC employs computer graphics to generate real-time, three-dimensional kinematic models of robotic workcells (Figure 3-7) to optimize robot/workpiece positioning, and to program the robot's movements off-line from the production area.

An engineering graphics workstation and Deneb IGRIP software is used to generate the workcell model and to manipulate the modeled workcell systems off-line to determine necessary robot controls. The robot model is manipulated and compared to the robot's work envelope to determine the optimum placement of the process equipments. This modeling process eliminates the repositioning of heavy equipment in the workcell that might be required when performing an on-site evaluation of the robot's ability to reach all locations on the work piece. The optimized modeling results are forwarded to process personnel, and robot programming is continued off-line without interfering with production personnel or efforts. The model simulation is also used to check for robot joint overtravels and collisions with the workpiece or other equipment. The finished robot program is then downloaded to the actual robot controller in the workcell.

Other facets of the workcell process such as nozzle spray paths are also determined off-line, to determine accurate spray control so that correct spray thickness can be achieved. Several processes that have been graphically modeled and implemented in PEC workcells include Spray-On Foam Insulation, Marshall Sprayable Ablator Research, an Advanced Robotic Development Cell, and the Solid Rocket Booster Refurbishment Mobile Robot.

Off-line development of robot and process equipment movements allows all workcell robotic processes to be programmed without conflicting with on-going work. It
also enables determination of optimal part and fixture placement within the workcell. MSFC has used its kinematic simulation capability to inject concurrent engineering practices into its workcell and process development effort with highly successful results.

SPECIAL TEST EQUIPMENT

Laboratory Portable Spectroreflectometer

The Materials and Processes Laboratory at MSFC is using a handheld instrument – called the Laboratory Portable Spectroreflectometer (LPSR) (Figure 3-8) – to measure reflectance of large surfaces in the field. This instrument can perform surface inspections on large or fixed parts which could not be easily tested in the laboratory.

The LPSR was developed by AZ Technology, Huntsville, Alabama, under contract for the MSFC. The LPSR uses varying wavelengths of light in the spectral range of 250 to 2500 nm to measure total hemispherical reflectance. Spectral reflectance values versus wavelength can be used to evaluate uniformity of surfaces or surface coatings. They can also be used to calculate solar absorptance. Solar absorptance values are used by engineers to calculate the amount of energy a space structure will absorb from the sun. This instrument has several advantages over laboratory versions. The most significant advantage is its portability. Laboratory versions of this instrument can weigh 300 pounds. The detection head of the LPSR weighs only 15 pounds. This allows the instrument to be taken into the field for evaluations of surfaces which are too large to be tested in the laboratory. It is also capable of testing various areas on a single sample to evaluate the surface uniformity. The minimum sample size of the LPSR is also smaller. The LPSR can measure sample discs as small as 0.5-inch. The LPSR has also reduced the scan time from approximately 20 minutes to less than two minutes. In addition, the sample rate has been increased for a greater signal-to-noise ratio resulting in enhanced accuracy and repeatability. Data collected by the LPSR can be displayed as it is collected or downloaded to a computer for storage or further analysis.

The MSFC identified a need for an instrument with greater flexibility. This instrument was developed for the MSFC and has enabled them to test surfaces which could not be easily tested in the past. The testing that is performed can also be performed with greater accuracy. This effort has resulted in an increase in the number of tests performed, the number of surfaces tested, and the quality of those surfaces.

3.4 FACILITIES

FACTORY IMPROVEMENTS

X-ray Calibration Facility

The ability to test and calibrate instruments prior to launch can reduce costly problems or repairs in space. The X-ray Calibration Facility (XRCF) at MSFC is a high vacuum test chamber designed for the calibration of X-ray mirrors and instruments. The test chamber is 24 feet in diameter and 75 feet long and is large enough to accommodate, in flight-configuration, any payload to be launched via the space shuttle. The test chamber can achieve vacuum levels of $10^{-7}$ torr or less from standard atmospheric pressure in six to seven hours. The X-rays are generated by electron bombardment and travel through a high vacuum guide tube. The guide tube is 1700 feet in length and varies in diameter from three feet at the X-ray source to five feet at the calibration chamber. The length of the tube allows calibration of X-ray mirrors with diameters in excess of 1.4 meters. The guide tube contains baffles which reduce scatter by eliminating X-rays that hit the sides of the guide tube.

Both the X-ray source and the test chamber are isolated from the surrounding building and the ground to remove possible interference from seismic disturbances. High vacuum levels are achieved first by mechanical pumps that are also isolated from the ground and the test chamber, and then by cryogenic and turbomolecular pumps.

The XRCF was modified in 1989 for the testing of the Advanced X-ray Astrophysics Facility. Parts of the old facility, in particular 1000 feet of guide tube and the mechanical pumps from the original test chamber, were reused, reducing the cost. Facility modifications and certification testing were completed within 23 months from the time project approval was received. The facility was also
designed to be utilized for not only advanced X-ray astrophysics work but also for the calibration of almost any X-ray equipment. In addition, the test chamber can be isolated from the guide tube to perform thermal vacuum testing of shuttle payloads, leak testing of space station modules, space simulation testing, and large space structure bakeouts. Extensive modifications to existing facilities were completed quickly and affordably. Commitment to the project by upper management and a design which utilized existing equipment made this possible. In addition, careful consideration of future potential needs allowed the design to make this facility useful for a variety of other functions.

**PRODUCTIVITY CENTER**

**Productivity Enhancement Complex**

The Productivity Enhancement Complex, or PEC, located within the Materials and Processes Laboratory at MSFC, is a complex of dynamic research cells developed on the needs of the space program. These cells are operated cooperatively by teams comprised of NASA, industry and university personnel.

In the early 1960s and 1970s, scientists and engineers at MSFC built prototypes of equipment incorporating new technology developed on site or under MSFC managed contracts. First article fabrication and test gave them manufacturing experience and allowed them to verify the design. It also enabled them to communicate effectively with the contractors who were to do the actual production. This changed in the late 1970s when MSFC was instructed to move first article fabrication and testing to contract facilities and to focus on technology development. MSFC lost the ability to communicate effectively with the contractors. Because they no longer shared manufacturing problems and experiences, the ability to transfer knowledge between technology development and manufacturing was reduced.

The PEC was established in 1980 in an effort to alleviate these problems. The research work cells within the PEC are staffed by employees from MSFC and a variety of contractors. The research efforts within these cells are focused on the development of advanced materials and manufacturing methods specific to program needs, with priority generally given to technology applicable to more than one program. Research focuses on the areas of environmentally safe materials development, welding and joining technology, bonding and contamination control, and process automation. One advantage of these research cells is that problems encountered in a contractor's manufacturing process can be resolved off-line where production schedules and resources are not compromised.

The PEC has provided many benefits to the MSFC and the aerospace community. It has enabled MSFC to team with industry and university personnel, providing a unique mechanism for technology transfer. Not only can technology be transferred between NASA personnel, industry, and academia, but a variety of contractors including Martin Marietta, Boeing, United Technologies, and Thiokol can transfer technology through their personnel located at the PEC. The PEC focuses on those technologies needing improvement, and due to the contractor involvement, these technologies can be easily integrated into production schedules. The research cells are independent of the other cells and any production lines. This independence aids in concurrent engineering, SPC, and off-line technology development. Work at the PEC has shown that every dollar invested in technology development and design has saved ten dollars in program costs. Since its start the PEC developed over 30 new technologies for an estimated cost savings of over one-quarter billion dollars.

**3.5 LOGISTICS**

**TRAINING MATERIAL AND EQUIPMENT**

Simulations for Procedure Verification and Training

Simulation efforts are extensively used by MSFC to verify mission equipment and procedures as well as training mission personnel. It is also used to validate mission documentation including the payload flight data file, payload operations handbook, joint operations interface procedures and all flight rules. The schedule of scientific activities during an orbiter mission are simulated beforehand to ensure that they are complete and accurate. The facility readiness and communications protocols are also validated. Through simulation efforts, costly mistakes during an orbiter mission can be avoided, resulting in the efficient use of mission resources and cost savings to MSFC's customers.

Simulations are also being used to train ground personnel and the crew. Ground personnel include those who will interface with the orbiter crew and the scientist whose experiment is being conducted aboard the orbiter. These workers gain experience in the procedures to follow when a scientist makes a request of the orbiter crew. Also, the ground personnel gain experience in interpreting the scientist's requests and putting them into the correct protocols for communication with the orbiter crew. After the science description, experiment training and integrated timeline training, the simulation exercise can be used to practice procedures for the crew in as realistic an environment as
possible. This is accomplished in a one-to-one scale mockup of the orbiter which is configured in the same way as the orbiter will be during the mission. Finally, crew and ground personnel also undergo simulator training in the handling of emergencies such as equipment failures during an experiment. This validates the procedures that have been laid out for the handling of such an emergency and familiarizes the crew with the procedures.

There are seven simulation sessions before each orbiter mission. Each successive simulation gives the involved personnel a chance to apply lessons learned from the preceding simulation. The first simulation involves the payload ground personnel only, then the payload personnel and the crew during the second simulation. As the simulations proceed, the scientists, Spacelab, Mission Manager and finally Mission Control are added to the simulations.

MSFC’s simulation sessions have proven to be invaluable to the successful completion of the orbiter mission. When the cost of getting an experiment to the point of flying on an orbiter mission is considered, the cost of the simulations is small.

Training Assessment Team Process

In an effort to improve planning for training, especially early in mission development, a Training Assessment Team (TAT) is assembled at the front end of the mission planning cycle. The Training Division at MSFC is responsible for payload operations training of the on-board payload crew and the ground based support team for various spacetab missions. Because each mission carries a different payload, each has different training requirements. Training assessment establishes the payload training requirements for a given mission. This includes simulator, crew training curriculum, simulations, and ground operations personnel training.

The TAT includes scientists, engineers, and training specialists that represent a wide variety of technical experience for the mission. The training personnel use a standard list of questions to gather general information from the scientists who are responsible for the experiments on the mission. This information is used to formulate preliminary training requirements which are used at formal TAT meetings as a basis for final requirements and curriculum development. Additionally, the scientists are informed of the importance of training to mission success. The use of this team to educate both the training team and the science community early in mission development has greatly improved the training planning process at MSFC.

The training curriculum at MSFC is also undergoing an improvement process. Generic courses are being created to cover the science overview, experiment operations, integrated operations, payload support training, MSFC mission independent training, and payload related activities. The goal is to create standardized training modules that can be adapted to meet all training requirements. Approximately 95 percent of these modules have been developed to date.

By implementing these changes, training personnel will be better informed on training requirements for a mission. Secondly, the scientists conducting the experiment and NASA will save time developing simulation and training tools. Finally, all parties will be informed of the training needs early in the planning process.

SUPPORT AND TEST EQUIPMENT

Integrated Facility Operations

MSFC is facing significant out-year increases in mission support functions for multi-purpose activities such as the Space Station Freedom, Spacelab, Payload, Shuttle, Advanced X-ray Astrophysics Facility, and development and validation functions. These programs all require sharing of limited resources at the HOSC.

In 1991, as a proactive response to business changes, MSFC began a year-long, business re-engineering effort to streamline processes and service functionalities. Starting with a focus on similar project support requirements, HOSC implemented generic operations that met common requirements, centralized operations and combined like job functions, and simplified procedures and coordination between functional groups. These changes have provided improved customer services by minimizing interfaces and maximizing operational responsiveness.

The current five year effort has four major elements of change. The first element includes understanding and redesign of operations, consolidating positional responsibility and reducing overall operational manpower. Secondly, the proposed implementation of an Integrated Systems Monitoring and Control System capable of centrally managing and controlling all hardware and software used within the HOSC facility is underway. Thirdly, based upon requirements forecast in computing resources, a centralized computer room with new data processing equipment is being installed. The Data Operations Control Room is being redesigned and will be capable of supporting five simultaneous orbital service activities. These carefully re-engineered changes will provide the MSFC’s Operational Center with the necessary resources to fulfill its increased mission requirements.
MANPOWER AND PERSONNEL

Payload Activity Scheduling

MSFC uses an internally developed FORTRAN program that runs on a VAX system to schedule all experimental activities during an orbiter science mission. The program, or Experiment Scheduling Program (ESP), operates in an x-windows style that allows the user to see the impact of changes to a schedule while editing it. Capable of scheduling up to 1,000 days, ESP is specifically tailored to the Spacelab, Shuttle and Space Station environment.

Before the schedule can be developed, several pieces of data are collected including the location of the orbiter at any time, the crew’s sleep schedule, equipment availability, and length of mission operations. This data is then entered into a database and a preliminary schedule is automatically generated by ESP. An average Payload Activity Schedule will have over 2,000 tasks – or steps – for the mission. To generate the schedule manually would require massive man-hours, and ESP represents a tremendous cost savings to MSFC and its customers. Once the preliminary schedule is generated, it is reviewed by the payload crew and scientists involved with the mission. The schedulers also maintain constant communication with the crew and scientists during all phases of the schedule development.

The system can accommodate rescheduling during the mission when it is necessary, such as in experiment equipment failure, or launch delay. This rescheduling process is performed every 12 hours during an active mission. Once a schedule is finalized for a 12-hour period, the payload crew’s activities are dictated by the Payload Activity Schedule. Continual feedback from the payload crew is used to determine what changes to the schedule for the next 12-hour period are necessary.

The use of ESP has been extremely successful and companies such as DLR from Germany, GE Government Services, and Martin Marietta are evaluating the system for incorporation into their programs.

3.6 MANAGEMENT

MANUFACTURING STRATEGY

Procurement Innovations

MSFC has maintained an active leadership role in promoting the continuous improvement (CI) philosophy and incorporating it as part of the Center’s culture. This philosophy is manifested in the Procurement Office where over 20 specific actions are in process to eliminate identified impediments and foster improvements throughout the acquisition process. The Procurement Office includes 183 employees, and over 30 percent participate on teams, with 10 percent serving as leaders and facilitators. Approximately 24 teams have been formed to examine work processes, formulate recommendations, and implement improvements throughout the Procurement Office. Leading the list of CI initiatives in the Procurement Office are the Science and Engineering Small Purchases project and the Unilateral Contract Actions project.

Science and Engineering Small Purchases
for non-ADP Equipment

This project’s goal was to determine where efficiencies could be implemented to reduce the total time required to procure goods and services initiated by the Science and Engineering Directorate. Analysis showed that steps performed in the current purchase process flow were executed sequentially, when many of the steps could be performed in parallel, thus reducing the cycle time. Also proposed was the expansion of the Credit Card System to engineers and scientists for small dollar purchases, eliminating a cumbersome and time delaying approval cycle. Although not fully implemented, preliminary data indicates that the median days to award small contracts have been reduced from the previous 75 days to 40 days.

Unilateral Contract Actions

The goal for this project centered on reducing the lead time of contract change order definitions. Analysis showed that the improved pricing reports, position memorandums, and office reviews of unilateral contract actions contributed significantly to the lead time of contracts. Countermeasures are being implemented to raise monetary threshold requirements for these reports, memos, and reviews. As a result, a goal to reduce lead times from 360 days to 180 days seems within reach.

Product Development Teams

MSFC developed the concept and guidelines for using Product Development Teams (PDTs) in the concurrent development of a specific product. The PDT, which is comprised of functional representatives, ensures an organized approach of delivering a product that meets the customer’s needs.

Core members on the team typically come from System Engineering, Product Support, Design Engineering, Manufacturing Quality, Material, Systems Test, and Cost. The team is at times complemented with personnel from Safety,
Facilities, and Human Factors. Each PDT focuses on a specific product—not the discipline. The PDT has management authority to develop product schedules, and approve requirements, drawings, RFP inputs, and development/verification plans. The PDT reports the product development progress and solves multi-functional problems that are presented.

Although dedicated full time to the PDT, members participate in other programs. The responsibility is placed on the member to determine what his or her availability is for other activities without interfering with the primary job as a PDT member. PDT members typically demonstrate a high level of credibility, good judgment, communication ability, and technical competency.

PDTs determine when meetings should occur and can range from daily to twice monthly, and MSFC has assigned one room for all PDT meetings. All core members attend, agenda and minutes are required, and an action item log is maintained. PDT Leaders meet monthly to exchange ideas about their team’s operations and make changes to the project plan. A PDT Engineering Council composed of Project Managers, Chief Engineers, Management of functional organizations, and the Program Manager meet as required to review progress of the PDTs.

PDTs have been successful due to employee empowerment by MSFC top management, as well as following established rules, using good team leaders and small teams (between four and 15 people), making decisions real-time, and applying the teaming concept. In addition, PDTs have provided:

- An organized approach of delivering a product that does what it is supposed to do
- Doing it right the first time
- Getting personnel involved that have a stake in the outcome
- Making decisions in full light of the total system concept
- Addressing issues from a broad sense and not just from a functional perspective
- Placing the emphasis on the product without loss of critical process control.

**Technology Transfer**

The MSFC Office of Technology Utilization pursues an aggressive technology transfer program aimed at the transfer of NASA derived technologies to state and local government, American industry, and academia. The Space Act of 1958 chartered NASA to disseminate the benefits of space research to all Americans. NASA has been a long time leader in technology transfer and has been credited with many consequent technologies due to its efforts through partnerships and patent licensing. Technology innovations are highlighted in the NASA Tech Briefs magazine, software in the COSMIC catalog, and assistance through its Regional Center.

With a goal to improve the domestic economy through the insertion of federal technology, Congress passed the Steven-Wylder Domestic Technology Transfer Acts of 1980 and 1986. This legislation mandates a higher level of participation by all federal laboratories and activities to make their technical expertise, facilities, equipment, and techniques available to state and local government, businesses, and educational institutions.

With passage of this legislation, the MSFC Office of Technology Utilization broadened its scope and accelerated transferring NASA-derived technologies. The Office uses several approaches to achieving successful technology transfer. Unique aspects of the technology transfer programs being pursued by this Office include its Outreach Programs in cooperation with most of the Southeastern Region of the United States. MSFC initiated a Memorandum of Understanding with Alabama, Tennessee, Mississippi, Louisiana, West Virginia, and Georgia to jointly sponsor workshops and symposiums aimed at increasing regional awareness of the benefits and potential applications of the space-related research available at MSFC, giving special attention to technical problems posed by the private sector. A Technology Utilization Assessment Board has been established to evaluate and process problem statements submitted by the private sector. In-reach programs have been initiated to raise the level of awareness within MSFC of on-going technology transfer and identify and solicit engineers and scientists to participate when problems arise.

The Office of Technology Utilization also manages several technology application projects and innovative discretionary projects that have high potential for applications in the private sector. Visibility is given to the technology transfer program through its publications in a variety of regional and local newsletters, the NASA Spacelink Database ((205) 895-0028), the NASA Tech Briefs magazine, and the NASA Tech Briefs Journal. The technology transfer success experienced by MSFC has been nationally and regionally recognized as the result of an outstanding program. The private sector has responded to the Outreach Program efforts by submitting and receiving responses to over 700 problem statements.

**Equipment Inventory Process**

MSFC has identified and implemented an inventory-by-grid-location method that has improved the efficiency and
effectiveness of its physical inventory process in support of regulations that require periodic inventories of all equipment valued over $1000 or sensitive items valued over $100.

The previous methodology at MSFC was to inventory the 50,000 pieces of equipment every three years, and the sub-installation inventoried another 30,000 pieces of equipment annually based on property accounts. The task was performed with insufficient personnel and the process was suspect as inefficient. Under the old inventory "account" method, inventory required extensive involvement of laboratory/office directors and property custodians, covered some 440 property accounts in 275 locations, caused duplicate inventory and physical area coverage, and required numerous visits to the inventory sites. Therefore, a team under the leadership of the Property Management Division was formed to investigate overhauling the process. Using the new inventory by location or grid method, the inventory process has eliminated difficulties such as:

- Participation by property custodians
- Extensive correspondence with laboratory/office directors and property custodians
- Location lists
- Potential for not scanning some equipment
- Duplicate scans and physical coverage of scans.

In addition, the new system facilitates joint inventory by both MSFC and sub-installation inventories, and provides faster updates. The new practice has also improved the span of control of equipment by conducting a complete inventory every year instead of every three years, thereby eliminating the annual 20 percent sensitive item inventory by the Activity Supply Officers and the annual 100 percent sensitive item inventory by the Property Custodian. As a result, the annual grid location inventory system has a projected labor savings of $500,000 over the first three years.

**Spacelab and Payloads Council for Excellence**

The working relationship between the Spacelab and Payloads Council for Excellence (SPACE) and MSFC contractors provides an example of excellent teamwork and cooperation. SPACE is a NASA/contractor team responsible for overall management of the Spacelab and Payloads TQM and continuous improvement activities. Its steering council was established in spring 1991. Major organizational team participants include the Payload Projects Office, Mission Operations Laboratory, Teledyne Brown Engineering, McDonnell Douglas, and Boeing Missile and Space Division.

The scope of SPACE activities encompasses all MSFC Payload Projects Office TQM/CI activities associated with the Spacelab and Space Station Freedom payload operations and payload integration tasks such as data processing and mission support operations. SPACE tracks key performance indicators in these areas such as customer satisfaction, technical quality, and cost and schedule management.

The council is empowered to identify high potential areas for improvement, charter process action teams (PATs) to work on the areas identified, periodically review PAT progress, and authorize implementation of recommended improvements. A SPACE survey of its user community in 1991 identified eight areas with high potential for improvement. Fifteen PATs were established to address the areas and implement improvements. A survey conducted in 1992 showed significant improvement in all areas.

One PAT dealt with the Spacelab database. Three MSFC organizations and four contractor organizations were represented on the team. Its mission was to evaluate information transfer among contractors and intra-center and inter-center database documentation and recommend a general process to provide verified Spacelab flight and ground databases. Even though the evaluation indicated that past and current operations were very successful, 19 significant areas of improvement were identified. Complex integrated systems of operational databases were documented and flow charted. The PAT recommended to the Council implementation of the identified improvements. These activities resulted in a strong spirit of teamwork between the members and organizations involved.

**MSFC/Contractor Quality and Productivity Partnership**

MSFC has created a culture and an environment with its contractors in which cooperation and communication foster improvements in quality and productivity. A key enabler of this process is the MSFC/Contractor Quality and Productivity (CQ&P) Partnership. Established in 1989, the Partnership acts as a catalyst for continuous improvement among MSFC, its contractors, and subcontractors. It functions in an advisory capacity focusing on sharing and issues. Working teams have been established to plan meetings and integrate activities, research educational opportunities, publicize activities, and evaluate and recommend resolution of issues. Forty contractors and all MSFC organizational elements are currently members.

Activities of the partnership include publishing a handbook and a quarterly newsletter, conducting formal surveys of participants, regular meetings, educational activities, and benchmarking. The CQ&P Partnership has activated an effective TQM/CI network for MSFC and its contractors and established a TQM/CI database for resources and
 contacts. It has served as a catalyst for incorporation of quality and productivity criteria in contracts and provided a forum for sharing ideas and lessons learned in TQM and continuous improvement techniques. The CQ&P Partnership has spawned numerous mini-partnerships and has been nominated by NASA for two national awards.

The effectiveness of MSFC’s CQ&P Partnership with its contractors is evident throughout the center. NASA personnel and employees of various contractors work together closely as a team. The adversarial relationship characteristic of government/contractor interactions is absent with the only emphasis on technology transfer, quality, and continuous improvement.

Customer Support Services

All NASA Civil Service employees and many NASA contractors rely heavily on the NASA Program Support Communications Network (PSCN). This system was implemented in 1984 and is serviced by MSFC and Boeing Computer Support Services (BCSS). A critical success factor to the successful implementation and high-quality servicing of such a complex system is attributed to the excellent partnership that exists between MSFC and BCSS.

The PSCN provides video teleconferencing, data transmission, voice teleconferencing, information, electronic mail, facsimile, telephone, and other inter-center services for some 100,000 people throughout the U.S. and internationally. Although the network provides capabilities from various resources, all services are provided to the user as a single image service.

This partnership is more than a contract requirement. Involved partners accepted changes in attitude and management style and accepted contractors and government on the same level with respect for the other’s resources and contribution. This relationship was nurtured through trust and open communications between MSFC and BCSS by sharing responsibilities, joint planning, and status reviews, joint participation in formulating the common vision, and focusing on the needs and expectations of the NASA users.

The common vision shared between the two parties recognizes the NASA user as the customer and NASA and BCSS are the suppliers with focus on the customer’s needs and expectations. User awareness is addressed through regularly scheduled briefings on the services available, and through the Information Systems Newsletter co-edited by NASA and BCSS.

As a result of this close partnership approach, the users realize a higher level of quality and more responsive service. The system is flexible and benefits from resource sharing through reduced duplication of effort and elimination of redundant processes between the two parties. However, its greatest benefit is that it provides a single image to all NASA users.

TECHNICAL RISK ASSESSMENT

Technical Penetration of Projects

The MSFC employs a number of techniques to maintain a high degree of technical involvement in outside-contracted projects. This involvement has contributed to the success of a number of projects based on the objective to develop a clear understanding of the systems and technical approaches developed by contractors.

Some factors that enable MSFC to maintain a high degree of technical involvement in projects include a diverse technical cadre, extensive laboratory facilities, ongoing in-house technical programs which maintain staff expertise, and the local availability of academic and contractor support.

The Center employs a “tiger team” concept to address serious problems. Examples of this approach include the design of the main engine controller; solving survivability problems; and after the Challenger accident, production of development flight instrumentation for the return to flight vehicles. The team had enhanced capabilities such as an increased authority to waive requirements and access to resources which enabled a major redesign within a year following the accident.

MSFC has been effective in establishing mechanisms by which it can effectively determine what individual contractors are doing. This has led to the early recognition of potential trouble areas and has allowed the staff to make meaningful suggestions of alternatives to resolve problems.
SECTION 4
INFORMATION

4.1 DESIGN
DESIGN PROCESS

Approach to In-House Design and Concurrent Engineering

MSFC has been tasked with structural design of the AXAF-S satellite, representing the first major orbital design effort to be performed by MSFC's Structural Design Division in over 20 years. Beyond the traditional design challenges, the Structural Design Division's Management is meeting the challenge of a young and growing skill level engineering work force.

During the 1960s and 1970s, the Structural Design Division used a direct hands-on design approach for multiple orbiter programs. As program funding and NASA funding decreased in the mid-1970s, the Design Group's core function migrated to a design critique approach where outside design agents and contractors developed, designed, and manufactured major hardware components and systems, and the Structural Design Division's function shifted to validation and review of designs for compliance.

This decay in the experienced skill base, combined with reduced staffing levels during these later time periods created a skill/experience level void. Most of the Structural Design Engineering staff has less than 10 years service, and only a few of the senior staff members have more than 25 years experience, leading to a challenge for the Division's management.

To meet this challenge, the MSFC's Design Division has developed a number of management practices to aid in developing the experience base of the work force. Utilizing the AXAF program as a catalyst for these skills development programs, select design teams are formed, following concurrent engineering principles, with a balance of skill levels and interdisciplinary engineering staff. These managerial practices, combined with formal engineering intern programs and informal mentoring partnerships will help MSFC's Structural Design Division address the dual objectives of meeting design schedules and promoting the skill level growth of the Structural Engineering work force.

DESIGN ANALYSIS

Control System Prototyping

MSFC applies Control Systems Prototyping (CSP) to meet stringent requirements. CSP dynamically isolates an experiment platform from the rest of the orbiting platform using a combination of hardware that is controlled with motion detecting devices and software. To accomplish this objective, several techniques are brought into play at the MSFC prototyping facility.

The first step is to dynamically model the orbiting platform and the experimental platform as a system. This includes the excitations that are a result of normal orbiter operations. To solve these multi-flexible/rigid body models, CSP facility personnel use the program Treetops that was specifically written for this purpose. The program, capable of running on any system that can support FORTRAN 77 programs, has a code that can be easily applied in any facility that requires the solution capabilities of Treetops.

The second step is to apply control theory to the system to eliminate unwanted motion at strategic locations; these locations come from modal analysis. Once the control system component locations have been determined, a prototype of the platform can be developed and tested. Prototypes at the facility are constructed of spare parts and fixtures that have been previously flown and are no longer in service.

Other technologies being applied to control systems at MSFC include passive dampening and piezoelectric effectors. Passive dampening is performed by sandwiching a dampening material between two pieces of structural materials such as aluminum or steel. The piezoelectric approach includes passing an accelerometer control current through the piezoelectric material so as to apply shear stresses which oppose the motion of the apparatus.

Hypervelocity Impact Facility

The Hypervelocity Impact Facility at MSFC is used to determine the effects of micrometeoroid and space debris collisions with various space hardware. The facility consists of two-stage light gas guns for the characterization, development, and qualification of hypervelocity impact shields for space vehicles and structures.
Any space hardware that will remain in space for extended periods of time will experience collisions with micrometeoroids and/or man-made space debris. These particles are moving at several kilometers per second and can do serious damage to space structures. To simulate impacts at this speed, the Hypervelocity Impact Facility uses a light gas gun (Figure 4-1). The light gas gun uses two stages and a light gas, such as hydrogen or helium, which is compressed to fire a projectile. The gun has two interchangeable barrels with inner diameters of 0.5-inch and 0.63-inch. Particle size can vary from 0.1-inch to 0.63-inch, and the weight can vary from 4 milligrams to 2.1 grams. The final velocity is dependent upon the powder charge, particle size and weight, and the type of gas used. Velocities between two and eight kilometers per second can be achieved.

The ability to perform high-speed impact studies is vital to the development of hypervelocity impact shields and structures. Particles moving at moderate speeds can penetrate thick panels or a series of panels, while faster particles may vaporize on impact. The damage done by hypervelocity particles is a factor of many variables, including velocity, mass, and angle of collision. Different types of structures are suited to protecting the space station or structure from different types of collisions. It is important that this technology be developed so that future space stations or structures are able to survive in the environment of space.

SOFTWARE

Flight Software Development Processes at MSFC

The software processes used to design and develop success-critical systems at MSFC have reached a high level of perfection. Software management and development at MSFC follow MMI 2410.11 (MSFC Management Instructions) based on the NMI 2410.6 (NASA Management Instructions) and MSFC Software Management and Development Requirements Manual (MM8075.1) which are similar to DoD 2167 procedures. Based on these, project software is classified into three categories - Category A, greater than 500 KSLOC; Category B between 25 and 500 KSLOC; and Category C less than 25 KSLOC. Software Data Requirements and reviews are tailored into four models based on criticality, size, and complexity (Figure 4-2 and Table 4-1). A spiral type versus waterfall type approach is used for complex system development. These software processes used at MSFC have led to successful flight software.

CONFIGURATION CONTROL

Configuration Management

Traditional Configuration Management (CM) practices have been employed by MSFC since the 1960s. The CM function shifted from a centralized CM function during times of high workloads (on Apollo mission support) to decentralized Project Management responsibility for CM function in the 1970s. In the early 1980s, with an incrementally increasing work load, the responsibility for CM shifted again towards a centralized function for the MSFC campus.

Working closely with Program Management, the CM staff interacts with both MSFC design personnel and an
Models for developing code are roughly determined by the previous logic, subject specific to customer requirements. Typically, models are predicted on past experience scheduling constraints and availability of human resources.

**Model 1**
1. Informal Requirements
   a) Typically Verbal
   b) Functional
2. Informal Design Reviews
   a) Verbal, Interactive
   b) Reactive to Modification Requests
3. Functional Testing Only
   a) Nominal Scenarios
   b) Minimum Set of Off-Nominal Scenarios
   c) No IV&V
4. No Documentation

**Model 2**
1. Informal Requirements
   a) Typically Verbal
   b) Functional
2. Informal Design Reviews
   a) Non-Standard Formats
   b) Reactive to Modification Requests
3. Functional Testing Only
   a) Nominal Scenarios
   b) Minimum Set of Off-Nominal Scenarios
   c) No IV&V
4. Documentation
   a) AS-Built Design
   b) Users Guide

**Model 3**
1. Formal Requirements
   a) Detailed
   b) Meets Standards
2. Formal Design Reviews
   a) Preliminary, Critical
   b) Meets Standards
   c) Baseline / Change Control
   d) Configuration Management
3. Functional Testing Only
   a) Nominal Scenarios
   b) Expanded Set of Off-Nominal Scenarios
   c) Separate, but not Independent, V&V
4. Formal Documentation
   a) Meets Standards
   b) Life Cycle Management

**Model 4**
1. Utilization of CASE Tool(s)
   a) Requirements Analysis
   b) Requirements Traceability
   c) Code Generation
   d) Configuration Management
   e) Life Cycle Maintenance
2. Formal Life Cycle Documentation
3. Prototyping
   a) Proof-of-Concept
   b) Feasibility Studies
4. Independent V&V
5. Exhaustive Testing
   a) Nominal Scenarios
   b) All Off-Nominal Scenarios
   c) Fault Tolerance
   d) Redundancy Management, if Required
   e) Recovery Procedures / Methods
   f) Timing Studies (In-Circuit Emulators)
   g) Unit (Module) Level / Functional
   h) Simulations
      - All Software
      - All Hardware
      - Hybrid
array of contractors providing system hardware to programs. The MSFC CM staff has developed and utilized several policy and procedural handbooks governing the initial program requirements and design modification process. MSFC uses a formal Configuration Control Board (CCB) consisting of a chairman and a panel of advisors representative of functional disciplines supporting each program or project.

The Configuration Management Division has been automating the various elements of CM for a number of years. During 1992, the group successfully implemented a change processing, tracking, and accounting system which includes Configuration Control Board Action item tracking, hardware and documentation change tracking and statusing, CCB Implementation Action Tracking and modification kits tracking, replacing two previous systems. During this time, the group has also migrated both computer hosts and databases to a better operating platform.

Future automation efforts include the incorporation of electronic forms generation and processing, electronic mail, automated routing and distribution systems, raster graphics storage and read capability, electronic approval, electronic graphics mark-up and editing (red-lining), and automatic action tracking closure notification through interfaces with other databases. The goal of this automation effort is to provide electronic conductivity of CM functional elements for both MSFC and its external supporting and participating agents (contractors and other NASA Centers).

Test Program Control and Change Process

A configuration control process has been established in the MSFC Propulsion Laboratory to provide uniform procedures for managing tests on rocket engines and other space-related hardware. The process is based on standard NASA configuration control procedures, but provides the flexibility which is needed in a test – such as non-flight – environment.

The change control process covers the “brick and mortar” portion of the facility, special test equipment, ground support equipment, and the test article such as a rocket engine. The program control process involves the identification of those items under change control, the establishment of facility and test article baselines, generation of a detailed test request, conduct of the test itself, and the evaluation of data after the test. A configuration control monitor is responsible for tracking all controlled documents. Documents used in the system include facility operation procedures, facility activation procedures, test and checkout procedures, test preparation sheets, test procedure deviation records, deviation logs, and an open item list which is a report that identifies open work, issues, and non-conformances.

The change control process has led to more effective management of tests while maintaining enhanced flexibility than is possible in a critical flight environment. The open item list has been especially effective in tracking the resolution of deviations from test to test.

4.2 TEST

DESIGN LIMIT

Battery Failure Analysis and Life Prediction

The Astronics Laboratory at MSFC is investigating the possibility of using frequency response techniques for enhancing destructive physical analysis of battery failures and non-destructive testing of batteries.

Battery failure is normally the result of a type of chemical migration. Determining that the migration has occurred is simple; however, identifying the root cause of the migration is quite difficult. Predicting or identifying which batteries are likely to fail from this chemical migration is not possible.

NASA MSFC has initiated studies to determine if the frequency response of a battery can be used for either failure analysis or for determining if latent defects are present. The capacitance between the electrodes and electrode plating in combination with the battery resistance impedance may be the critical factors. Measuring the frequency response of the RC circuits may indicate the life remaining in the battery. NASA is concentrating on lithium carbon monofluoride batteries, but the techniques could apply to any battery technology if the techniques prove effective.

LIFE

Electrical Power System Development

MSFC has developed simulated environmental testing to demonstrate the reliability of high voltage power processing units. The Center has been involved with the development of high power, high voltage (>100 vdc) electrical power systems with primary areas of effort being the power distribution units and batteries.

Two battery types under current investigation are Ni-Cd and Ni-H,. The Ni-H, batteries are new and show potential due to their high power-to-weight-and-size ratios. MSFC has developed test beds to simulate the operation of the battery in a space environment and is conducting life tests to determine battery reliability, reconditioning, schedules, and operational requirements. Data from battery testing is collected continuously on strip line recorders and automated data processing equipment that provides printouts of
key parameters and calculations. The analysis provides information beyond simple fail-or-pass data and provides information relating use and environment to performance. The study, combined with other efforts at MSFC such as the battery failure prediction techniques, offer advancements to all manufacturers using high power battery systems.

Hydrogen Test Facility

The Hydrogen Test Facility at MSFC is used to evaluate the mechanical properties of materials in the environments encountered in hydrogen propulsion systems. The facility includes four high pressure gaseous hydrogen and two low pressure liquid cryogenic hydrogen test cells. The facility has on-site supplies of propellant-grade cryogenic and gaseous hydrogen and high purity helium.

Hydrogen environments up to 10 kpsi pressure and 1800 degrees F can be attained while testing material properties such as tensile strength, shear strength, low and high cycle fatigue strength, fracture toughness, and crack growth rates. MSFC is currently involved in a series of round-robin tensile and fatigue tests with five industry facilities to establish an improved database on these properties in hydrogen environments.

TEST, ANALYZE, AND FIX

Database Information Systems

NASA conducts extensive research and because that data needs to be captured and used by NASA and its contractors, MSFC developed three integrated databases for use by the aerospace industry. These databases - the Materials and Processes Technical Information System (MAPTIS), NASA Environmental Information System (NEIS), and the Failure Analysis Information System (FAIS) - are relational and were written using the ORACLE Database Management System.

MAPTIS contains information on materials properties for both metals and non-metals; a Material Selection Handbook that identifies information such as materials composition, specifications, and test results; and a section for Special Materials which provides information on standards, foreign alloy cross reference, and test data.

NEIS is a system developed by NASA/MSFC to support its functions of the NASA Operational Environment Team. NEIS provides a central environmental technology resource drawing on all NASA Centers and contractor capabilities. It supports program managers who must ultimately deliver hardware compliant with performance and environmental requirements. It also tracks and assesses environmental regulations, uses, and new technology/products and materials, and it provides a channel of communications within the NASA Centers and between NASA and other agencies, aerospace contractors, and educational institutions.

The third database is the FAIS. MSFC maintains a complete diagnostic facility featuring a state-of-the-art electron optics laboratory and full service metallographic laboratory. The technical information systems include photophones, digital cameras, and scanners. MSFC is attempting to become the NASA Center of Excellence for structural materials failure analysis.

All of these database systems are user friendly and menu-driven with detailed help screens throughout. The systems are accessible from anywhere through a PC and modem. User accounts are available to all American industry upon submitting a request to MSFC and there is no charge for the service. The information in these databases is constantly changing, updated, and improved.

4.3 MANAGEMENT

MANUFACTURING STRATEGY

New Ways of Doing Business

The MSFC Engineering Cost Group, in association with Applied Research Inc. and Pittsburgh State University, completed a year-long cost quantification study to find out why it costs so much to do business and to recommend ways to do it better, cheaper, and faster. It was known as the New Ways of Doing Business (NWODB) study. The study group considered NWODB ideas from a broad range of sources including an MSFC NWODB QFD team, past studies, NASA managers and employees, and contractors (through surveys, literature, and interviews). The objectives of the analysis were to document NWODB recommendations, quantify potential cost and schedule benefits, and brief findings throughout NASA. The basic study with associated analyses and recommendations has been completed, documented, and extensively briefed. MSFC is committed to NWODB and is implementing it on all new programs such as the Advanced X-ray Astrophysics Facility and LUTE.

NASA’s way of business in the future must deal with a relatively constant budget. The trend on NASA programs is for cost and schedule to increase over time. These increases will be driven by increasing levels of performance and complexity, more levels of integration, volatility of requirements, and less funding stability.

The investigation found numerous recommendations already existed from past and current studies for improving NASA cost effectiveness. All of these studies have recommended process improvements that could result in significant savings. There were few new ideas generated by the
study, but most ideas had not produced savings on NASA programs because they had not been implemented. The findings of the study concluded that implementation of NWODB could reasonably be expected to reduce cost about 25 percent below NASA historical levels. NWODB could make a 15 percent cost reserve adequate – with 30 percent considered normal – with no cost growth expected and could lower program support costs.

Areas where improvements could be realized were categorized into the following six general topic areas:

- More extensive preliminary phase for the design, build, and test phases
- Multi-year funding stability
- Improved quality and management processes
- Improved procurement processes
- Advanced design methods
- Advanced production methods.

The greatest savings could be achieved by improving quality and management processes.

Continuous Improvement

The primary objective and vision of MSFC is to be the world’s leader in space transportation systems. The guiding principle in achieving this vision and the Center’s major goals are a commitment to excellence and continuous improvement. Other guiding principles include the importance of people, high ethical standards, equal opportunity, communications, teamwork, quality and safety, customer satisfaction, and education.

An MSFC CI Steering Council, established in May 1990, is composed of the Center Director, Deputy Director, and 13 top managers. This group provides TQM guidance, motivation, and oversight. A Continuous Improvement Office coordinates MSFC’s CI implementation activities. The Office supports Center organizational elements, provides assistance to the Steering Council, and serves as liaison with Center focal points. Extensive training of Center personnel has been completed or is in progress. Numerous CI teams have been established and are working on or have completed activities in process improvement, problem solving, Taguchi methods, product development, QFD, and others.

A strategic plan, vision, guiding principles, and goals have been established. An implementation plan has been prepared and culture study completed. Other accomplishments include establishment of a contractor partnership, teams establishment, employee training, and establishment of organizational focal points. Current and future activities include training trainers, preparing a CI guide, identifying success measures, and developing a software program to coordinate process action team accomplishments.
SECTION 5
PROBLEM AREAS

5.1 DESIGN

COMPUTER-AIDED DESIGN

Interdisciplinary Analysis Improvements

As in many industries, MSFC’s Structures and Dynamics Laboratory is currently applying finite element analysis and finite differencing analysis in the development of the designs for various orbiter component configurations and payload analysis. For any one design, the engineering analysis tools can span multiple disciplines including thermal, stress, dynamics, design, computational fluid dynamics, aerodynamics, aeroheating, and pointing and control.

To support each of the engineering analytical tools, multiple choices are available to the engineer including standard off-the-shelf commercial software and customized analytical software programs written by MSFC staff. However, common data must be shared by all the analytical software tools and current existing software will not allow for ease of data transportation to other software systems.

In response to this problem, the Structural Design Laboratory Division has written some translator programs to migrate from one software system to another (Figure 5-1); however, it is not an expeditious process. Manual re-

5.2 PRODUCTION

QUALIFY MANUFACTURING PROCESS

Chlorofluorocarbons and Solvent Replacement

The present federal target for elimination of CFCs, Halon and 1-1-1 trichloroethane is the end of 1995. This target date is in line with the Montreal Protocol agreement of 1-1-1 trichloroethane elimination and the projected production end for CFCs, Halon and 1-1-1 trichloroethane by the end of 1993.

MSFC and its primary contractors are major users of the ozone depleting materials in their thermal protection systems, cleaning processes, refrigerants and fire suppression equipment. In calendar year 1991, their programs used approximately one and a half million pounds of ozone depleting materials (Figure 5-2).

Although MSFC has taken the offense in finding substitutes for ozone depleting materials in all of its processes, it
has a shared problem with all of industry in that drop-in replacements do not exist for all applications and the time line to find acceptable replacements is short – December 1995.

NASA and its prime contractors have aggressively addressed the challenge together. Aqueous, semi-aqueous and terpin-based cleaners are being evaluated and cleaning requirements are being reviewed. The NASA Operational Environmental Team will continue to act as a clearinghouse to foster data sharing and eliminate redundancy through workshops and technical interchange meetings.
# APPENDIX A

## TABLE OF ACRONYMS

<table>
<thead>
<tr>
<th>ACRONYM</th>
<th>DEFINITION</th>
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<tr>
<td>AXAF</td>
<td>Advanced X-ray Astrophysics Facility</td>
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<td>BRDF</td>
<td>Bi-Directional Reflectance Distribution Function</td>
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<td>CCB</td>
<td>Configuration Control Board</td>
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<td>CM</td>
<td>Configuration Management</td>
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<td>CT</td>
<td>Computed Tomography</td>
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<td>DR</td>
<td>Data Requirements</td>
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<td>ECLS</td>
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<td>ET</td>
<td>Eddy-Current Tomography</td>
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<td>FAIS</td>
<td>Failure Analysis Information System</td>
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<td>HOSC</td>
<td>Huntsville Operation Support Center</td>
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<td>HSL</td>
<td>Hardware Simulation Laboratory</td>
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<td>IE</td>
<td>Integration Engineer</td>
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<td>INDERS</td>
<td>Integrated NDE Data Evaluation and Reduction System</td>
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<td>LPSR</td>
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<td>Program Support Communications Network</td>
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## ACRONYM DEFINITION

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## APPENDIX B

### BMP SURVEY TEAM

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<thead>
<tr>
<th>NAME</th>
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<tbody>
<tr>
<td>Larry Robertson</td>
<td>Crane Division</td>
<td>Team Chairman</td>
</tr>
<tr>
<td>(812) 854-5336</td>
<td>Naval Surface Warfare Center Crane, IN</td>
<td></td>
</tr>
<tr>
<td>Amy Scanlan</td>
<td>BMP Representative</td>
<td>Technical Writer</td>
</tr>
<tr>
<td>(206) 679-9008</td>
<td>Oak Harbor, WA</td>
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### TEAM A

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<tr>
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<tr>
<td>Kip Hoffer</td>
<td>Crane Division</td>
<td>Team Leader</td>
</tr>
<tr>
<td>(812) 854-3240</td>
<td>Naval Surface Warfare Center Crane, IN</td>
<td></td>
</tr>
<tr>
<td>John Greaves</td>
<td>Electronics Manufacturing</td>
<td></td>
</tr>
<tr>
<td>(317) 226-5665</td>
<td>Productivity Facility Indianapolis, IN</td>
<td></td>
</tr>
<tr>
<td>Don Hill</td>
<td>Naval Air Warfare Center</td>
<td></td>
</tr>
<tr>
<td>(317) 353-7221</td>
<td>Aircraft Division-Indianapolis Indianapolis, IN</td>
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### TEAM B

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<tr>
<td>Charles McLean</td>
<td>National Institute of Standards and Technology</td>
<td>Team Leader</td>
</tr>
<tr>
<td>(301) 975-3511</td>
<td>Gaithersburg, MD</td>
<td></td>
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<tr>
<td>Tirumalesa Duvvuri</td>
<td>Naval Command, Control and Ocean Surveillance Center</td>
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</tr>
<tr>
<td>(619) 553-5921</td>
<td>RDT&amp;E Division San Diego, CA</td>
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<tr>
<td>Michael McCune</td>
<td>Naval Warfare Assessment Center</td>
<td></td>
</tr>
<tr>
<td>(909) 273-4220</td>
<td>Corona, CA</td>
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### TEAM C

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<th>Name</th>
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<tr>
<td>Tim LaCoss</td>
<td>(518) 266-4566</td>
<td>U.S. Army Watervliet Arsenal, Watervliet, NY</td>
<td>Team Leader</td>
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<tr>
<td>John Guy</td>
<td>(317) 226-5630</td>
<td>Electronics Manufacturing, Indianapolis, IN</td>
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<tr>
<td>John Carney</td>
<td>(703) 602-3822</td>
<td>Naval Surface Warfare Center, Bethesda, MD</td>
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### TEAM D

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<tr>
<td>Richard Purcell</td>
<td>(703) 271-0366</td>
<td>BMP Representative, Washington, DC</td>
<td>Team Leader</td>
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<tr>
<td>Larry Halbig</td>
<td>(317) 353-3838</td>
<td>Naval Air Warfare Center, Indianapolis, IN</td>
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</table>
APPENDIX C

NAVY CENTERS OF EXCELLENCE

Automated Manufacturing Research Facility
(301) 975-3414

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

Electronics Manufacturing Productivity Facility
(317) 226-5607

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

National Center for Excellence in Metalworking Technology
(814) 269-2420

The National Center for Excellence in Metalworking Technology (NCEMT) is located in Johnstown, Pennsylvania and is operated by Concurrent Technologies Corporation (CTC), a subsidiary of the University of Pittsburgh Trust. In support of the NCEMT mission, CTC’s primary focus includes working with government and industry to develop improved manufacturing technologies including advanced methods, materials, and processes, and transferring those technologies into industrial applications. CTC maintains capabilities in discrete part design, computerized process analysis and modeling, environmentally compliant manufacturing processes, and the application of advanced information science technologies to product and process integration.

Center of Excellence for Composites Manufacturing Technology
(414) 947-8900

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

PROGRAM MANAGER'S WORKSTATION

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

- **KNOW-HOW** is an intelligent, automated method that turns "Handbooks" into expert systems, or digitized text. It provides rapid access to information in existing handbooks including Acquisition Streamlining, Non-Development Items, Value Engineering, NAVSO P-6071 (Best Practices Manual), and the DoD 5000 series documents.

- **TRIMS** is based on DoD 4245.7-M (the transition templates), NAVSO P-6071 and DoD 5000. It identifies and ranks the high risk areas in a program. TRIMS conducts a full range of risk assessments throughout the acquisition process so corrective action can be initiated before risks develop into problems. It also tracks key project documentation from concept through production including goals, responsible personnel, and next action dates for future activities in the development and acquisition process.

- **The BMP DATABASE** draws information from industry, government, and the academic communities to include documented and proven best practices in design, test, production, facilities, management, and logistics. Each practice in the database has been observed and verified by a team of experienced government engineers. All information gathered from BMP surveys is included in the BMP DATABASE, including this survey report.

- **BMPNET** provides communication between all PMWS users. Features include downloading of all programs, E-mail, file transfer, help "lines", Special Interest Groups (SIGs), electronic conference rooms and much more. Through BMPNET, IBM or compatible PC's and Macintosh computers can run all PMWS programs.

- To access BMPNET efficiently, users need a special modem program. This program can be obtained by calling the BMPNET through your communications software by dialing (703) 538-7697 for 2,400 baud modems and (703) 538-7267 for 9,600 baud and 14.4 kb modems. BMPNET operates with any standard modem program that can emulate a VT-100/200 terminal. When asked for a user profile, type: Download <return>. This will automatically start the Download of the PC DOS version of our special modem program. You can then call back using this program and access all BMPNET functions (except receiving mail). The General User account is:

  USER PROFILE: BMPNET
  USER I.D.: BMP
  Password: BMPNET

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

PREVIOUSLY COMPLETED SURVEYS

BMP surveys have been conducted at the companies listed below. Information gathered from all BMP surveys is included in the Best Manufacturing Practices Network (BMPNET). Additionally, a calendar of events and other relevant information are included on the BMPNET. Copies of older survey reports may be obtained through DTIC or by accessing the BMPNET. Requests for copies of recent survey reports or inquiries regarding the BMPNET may be directed to:

Best Manufacturing Practices Program
2101 Crystal Plaza Arcade
Suite 271
Arlington, VA 22202
FAX: (703) 696-8480

COMPANIES SURVEYED

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

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

Harris Corporation
Government Support Systems Division
Syosset, NY
September 1986

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

ITT
Avionics Division
Clifton, NJ
September 1987

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

General Dynamics
Fort Worth Division
Fort Worth, TX
May 1988

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

General Dynamics
Pomona Division
Pomona, CA
August 1986

IBM Corporation
Federal Systems Division
Owego, NY
October 1986

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

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

Motorola
Government Electronics Group
Scottsdale, AZ
March 1988

Texas Instruments
Defense Systems & Electronics Group
Dallas, TX
June 1988
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<td>College Park, MD</td>
<td>June 1989</td>
</tr>
<tr>
<td>Engineered Circuit Research, Incorporated</td>
<td></td>
<td>Milpitas, CA</td>
<td>July 1989</td>
</tr>
<tr>
<td>Lockheed Aeronautical Systems Company</td>
<td></td>
<td>Marietta, GA</td>
<td>August 1989</td>
</tr>
<tr>
<td>Westinghouse</td>
<td>Electronic Systems Group</td>
<td>Baltimore, MD</td>
<td>September 1989</td>
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<tr>
<td>Rockwell International Corporation</td>
<td>Autonetics Electronics Systems</td>
<td>Anaheim, CA</td>
<td>November 1989</td>
</tr>
<tr>
<td>Hughes Aircraft Company</td>
<td>Ground Systems Group</td>
<td>Fullerton, CA</td>
<td>January 1990</td>
</tr>
<tr>
<td>MechTronics of Arizona, Inc.</td>
<td></td>
<td>Phoenix, AZ</td>
<td>April 1990</td>
</tr>
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<td>Technology Matrix Consortium</td>
<td></td>
<td>Traverse City, MI</td>
<td>August 1990</td>
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Textron Lycoming
Stratford, CT
November 1990

Naval Avionics Center
Indianapolis, IN
June 1991

Kurt Manufacturing Co.
Minneapolis, MN
July 1991

Raytheon Missile Systems Division
Andover, MA
August 1991

Tandem Computers
Cupertino, CA
January 1992

Conax Florida Corporation
St. Petersburg, FL
May 1992

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

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

Norden Systems, Inc.
Norwalk, CT
May 1991

United Electric Controls
Watertown, MA
June 1991

MagneTek Defense Systems
Anaheim, CA
August 1991

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

Charleston Naval Shipyard
Charleston, SC
April 1992

Texas Instruments
Semiconductor Group
Military Products
Midland, TX
June 1992

Watervliet U.S. Army Arsenal
Watervliet, New York
July 1992

Naval Aviation Depot
Naval Air Station
Pensacola, Florida
November 1992