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AEROSPACE ROBOTIC IMPLEMENTATIONS: An Assessment and Forecast

SEPTEMBER 1986

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ABSTRACT

**ROBOTIC IMPLEMENTATIONS:
AN ASSESSMENT AND FORECAST**

This effort is a continuation of Phase I, a technology assessment and forecast, and identifies current and future robotics implementation opportunities within the aerospace industrial base sectors. The results are arrayed in three matrices:

CURRENT APPLICATIONS, provides a baseline of robotics technology in use across industry and highlights differences between aerospace and non aerospace utilization of robotics.

CURRENT OPPORTUNITIES, identifies processes suitable for robotics, analyzes this lack of utilization, and describes the cost, capacity, quality, and surge and mobilization impacts of robotics implementation.

FUTURE OPPORTUNITIES, identifies potential applications within the next 5 years and discusses barriers to more rapid implementation in manufacturing.

In the course of analysis, issues surfaced which apply across the aerospace industry. These issues are used to summarize the findings of this effort.

PREFACE

This study was performed by DHR, Incorporated under contract (No. F33657-85-D-0111, Delivery Order 0001) to the Aerospace Industrial Modernization (AIM) Office of the Air Force Systems command. The Project Manager for this effort at the AIM office was Mr. Fredrick C. Brooks.

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EXECUTIVE SUMMARY

I. INTRODUCTION

The readiness and sustainability posture of many of today's weapons systems is directly tied to the capabilities and capacities of the industrial base. Initiatives designed and implemented to improve the productivity and capacity of existing manufacturing processes are prompted by an immediate need to improve the wartime posture of Air Force weapons systems as well as a desire to generically enhance an industrial sector.

The Air Force is continuing its efforts to reduce acquisition and life cycle costs and improve the preparedness posture of systems dependent upon the industrial base. As part of this objective a two-phased investigation was initiated to determine the potential for modernizing selective portions of the industrial sector through the introduction of robotics systems.

The Phase I effort identified industrial robotics application, ongoing research and development for robotics technology and application opportunities, and provided a fifteen-year forecast of future technological applications. Phase I was completed in July 1984 and the findings are contained in the now widely distributed report: Robotics Technology: An Assessment and Forecast; Air Force Systems Command, Aerospace Industrial Modernization Office, Dayton, Ohio, July 1984.

This report (Phase II) is a follow-on to Phase I and identifies current and future robotics implementation opportunities within the aerospace industrial base sectors. Information has been compiled and assessed in a manner that provides for correlations to Air Force Systems Command's (AFSC) Product Division areas of responsibilities.

Data to accomplish this effort were obtained by surveying prime and subcontractors throughout the entire aerospace industrial sector. The Air Force Systems Command's product divisions assisted in the identification and selection of companies to ensure applicability to the differing needs of the various product divisions. A total of 53 contractors were identified for participation in this effort.

Data obtained from these contractors were used to identify and characterize both current and future robotic implementation opportunities. The opportunities identified are presented in an unprioritized format. The report does, however, describe a prioritization methodology for use by AFSC's product divisions that will allow them to address their particular needs and establish their individual priority schemes. This methodology, as well as the methodology used to analyze and array the data, is described below.

II. METHODOLOGY

Data collection and analysis techniques were structured to provide insight into current applications, current opportunities and future opportunities, and are arrayed in three matrices.

A. The Current Applications matrix provides a baseline of off-the-shelf robotic technology in use across industry and highlights differences between aerospace and non-aerospace utilization of robotics.

B. The Current Opportunities matrix provides an identification of plant processes suitable for robotization, an analysis of why the robotic implementation potential has not been realized and describes how implementation of robotics can affect cost, capacity, quality, and surge and mobilization support.

C. The Future Opportunities matrix identifies potential applications within the next five years and discusses the existence of barriers thwarting a more rapid transition to robotics in manufacturing processes.

The implementation opportunity data within these matrices represents a broad range of possible applications. To be of maximum benefit, the data must be prioritized to reflect individual product division needs and constraints. Prioritization criteria to be used in the assessment of both current and future opportunities include:

- a. Cost reduction
- b. Quality enhancement
- c. Throughput improvements
- d. Technical feasibility
- e. Ease of implementation
- f. Application emulation
- g. Reduction of skilled labor
- h. Required technical support level

Each of these factors must be weighted according to the particular product division needs, so that assessment of the implementation opportunities against these criteria will yield a prioritization meaningful to the product division.

III. FINDINGS

Figures ES-1 and ES-2 summarize, respectively, the current and future implementation opportunities by aerospace sector. The manufacturing processes on the left of each figure are grouped into ten functional areas, representing an Applications Axis. The entire Applications Axis is presented in detail in Appendix A. As would be expected, the aircraft sector represents the largest percentage of the implementation opportunities for the aerospace industry, followed closely by the propulsion and electronics sectors.

GENERAL FINDINGS - CURRENT OPPORTUNITIES

	AIRCRAFT	ARMAMENT	BALLISTIC MISSILE	ELECTRONICS	PROPULSION	SPACE
1.0 WELDING	Shaded	Shaded		Shaded	Shaded	
2.0 INSPECTION	Shaded			Shaded	Shaded	
3.0 ASSEMBLY		Shaded		Shaded		
4.0 COATING	Shaded	Shaded		Shaded	Shaded	Shaded
5.0 SEALING/ADHESIVE				Shaded		
6.0 SURFACE PREP	Shaded					
7.0 MATERIAL REDUCTION	Shaded		Shaded		Shaded	
8.0 CASTING	Shaded				Shaded	
9.0 FORGING	Shaded					
10.0 MATERIAL HANDLING	Shaded	Shaded		Shaded	Shaded	

Figure ES-1: Current Opportunities

GENERAL FINDINGS - FUTURE OPPORTUNITIES

	AIRCRAFT	ARMAMENT	BALLISTIC MISSILE	ELECTRONICS	PROPULSION	SPACE
1.0 WELDING						
2.0 INSPECTION						
3.0 ASSEMBLY						
4.0 COATING						
5.0 SEALING/ADHESIVE						
6.0 SURFACE PREP						
7.0 MATERIAL REDUCTION						
8.0 CASTING						
9.0 FORGING						
10.0 MATERIAL HANDLING						

Figure ES-2: Future Opportunities

Following is a brief textual description of the current and future implementation opportunity status of each aerospace sector. These descriptions present highlights of the current robotics implementations as well as the current and future implementation opportunities.

1. Aircraft

Current implementations are found to exist in many structural process such as welding, riveting and drilling. Opportunities currently exist to expand robotics implementation in areas of metal and tungsten inert gas welding, laser cutting, aluminum structural casting and hot die forming. Many opportunities are forecasted to be available for implementation within the next five years, ranging from assembly processes for canopies and wire harnesses, to sealing wing surfaces, to composite fabrication processes such as automated tape lay-up and filament winding.

2. Armament

Current robotic implementations in the Armament sector consist primarily of material handling tasks, including an X-ray inspection application. Based on robotics usage in other industrial sectors, many current implementation opportunities exist, including laser welding, simple and complex assembly tasks, and material handling of explosives. Additionally, future implementation opportunities exist in the areas of welding, assembly and material handling of explosives.

3. Ballistic Missile

The Ballistic Missile sector currently has robotic implementations for assembly, rivet/derivet and adhesive spray tasks. In addition to further use of these implementations, there exists several current implementation opportunities for robotic material reduction tasks such as milling, routing and drilling. Future implementation opportunities for this sector include material handling and assembly of explosive units, advanced machining of rocket motor casings, and composite filament winding for rocket motor casings.

4. Electronics

Due to its partial commonality with commercial industry, the electronics sector exhibits a relatively high utilization of current robotic technology, including welding, circuit board assembly functions, cable harness assembly, circuit board masking, and kitting. Current implementation opportunities exist in these areas as well as discrete component test, circuit board test, and material handling tasks. As robotic positioning and gripper functions become more accurate in the next one to five years, robotics are projected to play a larger role in hybrid circuit assembly.

5. Propulsion

Current robotic implementations in the propulsion sector are concerned primarily with the processing of disk and turbine blades: inspection, thermal spray coating, heat treating, sonic machining, isothermal forging,

and part washing. While these areas also represent current opportunities, robotic implementation can be expanded into the areas of welding and composite manufacturing. Future implementation opportunities continue to revolve around disk and turbine blade processing, including advanced inspection, laser drilling, and automated part handling.

6. Space

Due to the advanced part complexity and small production runs typical of the space sector, robotic technology has not penetrated deeply into this sector. Spray coating of specialty materials has been the most significant robotic implementation to date, and represents the most promising current implementation opportunity. Future implementation opportunities will consist primarily of advanced inspection and material processing technologies.

IV. SUMMARY

During the course of data analysis several issues surfaced which are applicable at an industry-wide level. These issues can be used to summarize the findings of this study, and are presented below.

1. Aerospace vs. Non-aerospace Application. While the aerospace industry is frequently at the forefront of robotic technology R&D, the overall rate of utilization lags behind that of commercial industry. This finding, consistent with that of the Phase I report, is driven largely by the small production runs typical of aerospace industry. As robotic technology becomes less expensive and more cost effective at the lower production rates, the level of utilization within the aerospace industry will increase.

2. Electronics Applications. Although not stated explicitly in Section III, electronics applications are relevant to all sectors of the aerospace industry, either directly, as in the case of avionics systems for the aircraft sector, or indirectly, as in the case of electronic subsystems for engine control in the propulsion sector. Due to the universal nature of electronics, advances in electronics fabrication, assembly and test techniques will be felt across the entire aerospace industry. For this reason, robotics research and development programs directed towards electronics fabrication, assembly and test should be a high priority.

3. Flexible Manufacturing Systems. Robots as stand-alone systems are gradually giving way to more complex flexible workstations, i.e., groups of automated machinery capable of being controlled to function in unison. In the small batch environment of the aerospace industry, the flexibility gained from an automated workstation is much more beneficial than that from a single dedicated robot. While stand-alone robots will still have their place in many processes, more attention should be paid to incorporating robots into flexible workstations.

4. Technology Transfer. Among the industry participants in this study there seemed to be some confusion as to current versus future implementation opportunities. This stemmed from a lack of understanding of the current state-of-the-art of robotic capabilities. For example, some companies were avoiding robotic development programs that they perceived beyond the current technology capabilities, when in fact those processes had already been implemented by other companies. Comprehensive technology transfer programs will help to balance the level of robotic utilization across the aerospace industry.

1.0 Introduction

This document is part of a long range Air Force plan to guide the implementation of robotic technology into the aerospace industrial base. It has long been recognized that the defense posture of the United States rests heavily on the ability of the industrial base to supply the state-of-the-art weapon systems to the military. Furthermore, the ability of the industrial base to supply sufficient quantities of crucial weapon systems in an emergency has recently been questioned. In response, the military has embarked on efforts to sponsor the insertion of advanced manufacturing technology into the defense industrial base. Within the context of these efforts, the Air Force has recognized the benefits of implementing robotic technology into the industrial base, and is developing a plan to guide this implementation. The goal of the Air Force is not just to advance the implementation of robotics into industry, but to realize tangible benefits from this implementation. Specifically, the Air Force goals for implementation of robotic technology are the reduction of weapon system acquisition costs, improved life cycle cost-effectiveness, and an improved defense preparedness posture.

Reduced Acquisition Cost

A significant benefit derived from implementation of advanced manufacturing technology is increased efficiency of production. Efficiency in production has many aspects, ranging from reduced scrap to improved material ordering schedules and reduced leadtimes. The effect of these improvements is the reduction in unit costs of production. Whether this reduction results in a reduced selling price is heavily affected by the customer base. For commercial sales, the market sets price and reduced cost produces higher profit. For the DoD market, contract negotiation sets price, and cost of production is a major consideration in determining the unit cost. As a result, improved efficiency in manufacture can directly affect the unit cost paid by the government. However, costs of investments made to increase efficiency must be recovered at some point, and investments in expensive technology can increase the unit cost.

Improved Life Cycle Costs

While there is a significant amount of effort spent to reduce the acquisition cost of weapon systems, life cycle costs can often outweigh production costs. Reduced life cycle costs is an equal, if not greater goal for achieving cost effective improvements. Two key factors affecting the life cycle costs of a weapon system are inspection and maintenance, both planned and unplanned. The quantity of planned and unplanned inspection and maintenance performed is directly related to the quality and consistency of the manufacturing process. The cost of maintenance, then, can be attacked through improved manufacturing technology. The most striking effect of robotics and other automation on manufacturing is uniformity. The level of uniformity achieved by automated systems reduces unanticipated failures by improving quality control, and introduces a level of predictability not

achievable by labor intensive manufacturing methods. This improved performance can be used to reduce scheduled inspection and maintenance while maintaining the same level of confidence in the system reliability. The key to understanding the potential maintenance reduction is to recognize that a constant two percent failure rate per month is likely to be less costly to support, in terms of scheduled maintenance, than a one percent per month average failure rate that occasionally runs as high as five percent.

Improved Defense Preparedness Posture

More efficient manufacturing affects the preparedness stature of our Armed Forces in a number of ways. The most obvious is that by reducing unit costs, more resources become available for other acquisitions. Having more weapon systems on hand at the beginning of an emergency improves the ability of the nation to respond. Similarly, availability of sufficient quantities of expendable items helps to cover the time required for manufacturers to ramp-up production. The direct effects in peacetime are just as important; increased opportunities for training and exercises, and more use of live rounds during drills. This results in more than increased experience for personnel, it performs a spot check of weapon system function and performance, as well as maintaining a warmer production base. The other impacts on preparedness of utilizing advanced technology can be beneficial or detrimental. Flexible Manufacturing Systems can greatly enhance preparedness by allowing rapid change in product mix to reflect actual requirements without requiring the construction of new production facilities or lines. Similarly, use of Computer-Numerically Controlled (CNC) equipment allows rapid expansion of usable production capacity due to the relative ease of transfer of control tapes. However, the use of robotic technology can significantly reduce the Surge production capability. The newer (and more expensive) equipment is more likely to be operated on a multi-shift basis under peacetime conditions in order to recover investment rapidly. As a result, newer equipment generally has less downtime built into its schedule, and cannot double or triple throughput simply by adding additional personnel. In addition, advanced production machinery can reduce preparedness because it can suffer from many of the same ills as the weapon systems it produces: long lead time for acquisition, foreign dependency, and the need for highly skilled support personnel.

Long Range Planning for Manufacturing Technology

One of the major areas of manufacturing technology from which the Air Force feels significant benefits can be derived is industrial robotics. This is a relatively new field of manufacturing technology, and its role in the industrial base is still being defined. However, the increasing utilization of robotics by the commercial sector in cost-effective ways indicates that potential implementations are available today. The Air Force, recognizing the complexity of implementing new manufacturing technology, is developing a long range program to increase the implementation of robotics in aerospace manufacturing. Current aerospace implementations have resulted in significant benefits to the Air Force, in terms of reduced acquisition costs, increased

quality, and decreased leadtimes. The effective use, however, of the wave of automation, robotics and Flexible Manufacturing that is building in the commercial sector requires a long range strategy that reflects the shift from ad-hoc stand-alone robotic cells to robots integrated into a manufacturing system planned from the top down. The Air Force is following such a strategy, beginning with the assessment and forecast of robotic technology in the first phase of this effort and continuing with the implementation assessment and forecast of this second phase.

Robotics - Phase I

The first phase of the current Air Force effort to evaluate robotic technology resulted in the predecessor to this report, Robotics Technology: an Assessment and Forecast (Air Force Systems Command Aerospace Industrial Modernization Office, July 1984). This report was the first stage of a phased effort to perform an examination of: industrial robotics usage, worldwide R&D for robotic systems and components, and differences in utilization by industry. The report was intended to be a resource for Air Force decision makers by presenting sufficient introduction and background to make the subtleties of the information accessible to interested personnel within the manufacturing community. The two major objectives of this first stage effort were to compare and contrast aerospace usage of robotics with other industries, and to forecast the technological developments and capabilities that are likely to affect aerospace usage.

The results of the industry comparison indicated that aerospace lagged behind other industries (most notably the automotive industry) in implementing robots. This conclusion was easily arrived at by reviewing a simple count of in-place robots, but the underlying causes for the lag were less obvious. Aerospace manufacturers as a group operate in a very different environment than non-aerospace manufacturers. As an example, the technological demands placed on the manufacturing processes are normally higher (e.g., closer tolerances) for aerospace products, and the quantities of production are typically lower. As a result, many of the successful robotic implementations in non-aerospace manufacturing are not directly transferrable to aerospace applications. Even if such a transfer is technologically feasible, the different economic factors such as batch size may work against transferability of this technology.

While economic and contractual barriers to technology transfer were identified in the first phase report, the concentration was on technological barriers to aerospace use of industrial robots. After describing the level of performance available from commercial (as opposed to R&D) robotic systems, the study examined trends in research and development in academic and manufacturing environments in the U.S. and abroad. By analyzing the areas of greatest activity, highest funding, and progress as presented in journals and at meetings, the study predicted near and far term technological developments, and their affects on robotic performance. This prediction, coupled with the report's specification of performance barriers by application, was used to identify a category of "high growth" applications. These were the applications that are expected to show dramatic growth in the near future

as specific performance barriers are overcome.

Robotics - Phase II

This stage of the Air Force long range robotics implementation plan requires a narrowing of focus from the Phase I effort. With the previous work as a base, the next requirement for Air Force planning is the identification of specific aerospace robotic implementations, ideally those where the investment is moderate, the benefit substantial, and the probability of success very high. In addition, the results must reflect the Air Force organization by being analyzed and presented in the framework of the Systems Command Product Divisions. The Product Division orientation has been incorporated from the beginning of the effort, as will be described in Section 2.0.

The results of the information gathering and interpretation confirm that there are opportunities for robotics in aerospace manufacturing that are primarily inhibited by lack of information transfer. Specifically, there are contractors who are interested in implementing industrial robots for specific applications, but who have not begun because they are not sure how to begin. Other contractors would like to install robotic systems, but the costs of demonstrating feasibility, performing preliminary design and testing, and defining the investment/payback structure is prohibitive. The proprietary nature of development work and the competitive environment of U.S. industry discourages the easy transfer of this technology and may preclude cross transfer of information.

In summary, the major goal of this phase of the study effort is to generate information transfer. Those Air Force personnel having oversight for or involved in factory modernization efforts should be able to use these study findings to assess possible robotic implementation opportunities within their sphere of interest. Furthermore, the presentation of information is structured to allow Air Force personnel to key information on Air Force criteria, such as affected weapon systems, for assessing the benefits achieved by specific implementations.

2.0 Study Methodology

This section describes the methodology used in the performance of this effort, from conceptualization to analysis of collected data. The methodologies for each the major functional units of this study include: development of the matrix approach, data gathering techniques, incorporation of Air Force Product Division input, forecasting, and prioritizing of opportunities.

2.1 Matrix Approach

The methodology used to perform this study was largely data-driven, i.e., the type and amount of data collected dictated a methodology which would allow for the collection and organization of the data in a manner that facilitated analysis. The methodology chosen consisted of the development and use of three comprehensive data structures, or matrices, used to direct the collection efforts and aid in the analysis of the data. By developing the data structures before the data collection began, data collection efforts could be more accurately focused, thereby increasing the efficiency of the efforts. As data were collected, they were sorted into the appropriate position of the applicable matrix. As a result of the structured format of the matrices data in specific areas carried, by implication, important information. A total of three matrices were used in the study, with each matrix using and building upon information from a previous matrix. Specifically, Matrix 1 contains current application data, Matrix 2 contains current opportunity data, and Matrix 3 contains future opportunity data. Detailed descriptions of each of the matrices' information and relation to the overall study follow along with a graphic illustration of the matrices in Figure 2-1.

Each of the three matrices share a common Detailed Application Axis. Because the basic unit of analysis for this study is the individual robotic application, this allows for the direct comparison of application information between each of the matrices. Because information gaps in the matrices were as important to the study as data collected, it was critical to make the application axis as comprehensive as possible. Additionally, because people describe robotic applications differently, it was necessary to have the application axis as universal as possible. For example, the axis had to not only differentiate applications on the basis of differing technologies, but also be structured to allow for grouping of similar applications. An additional difficulty in categorizing robotic applications arises from the different point of view of robot producers versus robot end users. While a robot producer might describe a robot application in terms of the robotic technology used, a robot end user would describe the same application in terms of the manufacturing function performed. It was therefore necessary to develop the Detailed Application Axis to be able to reflect both of these points of view. To effectively accomplish this, a draft axis was developed and submitted to robot producers and end users, as well as Air Force representatives, for comment. The final Detailed Application Axis is presented as Appendix A.

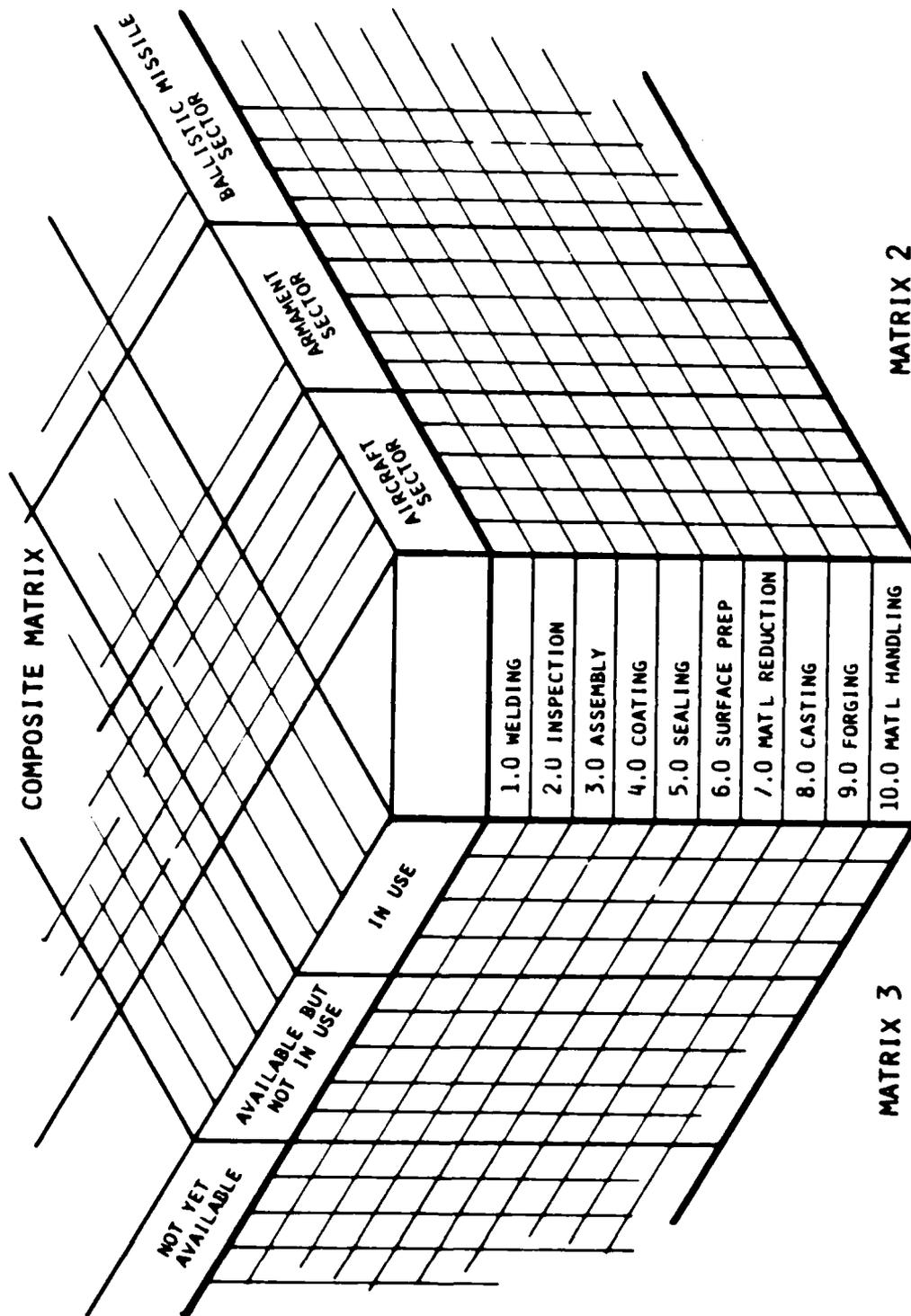


Figure 2-1: Data Organization

Matrix 1 - Current Applications Matrix

The purpose of Matrix 1 is to provide a baseline of robotic usage across industry. The importance of this matrix is two-fold: to establish a baseline of the "off-the-shelf" robotic technology currently available, and to highlight any differences between aerospace and non-aerospace usage of robotics. Areas of robotic applications that have penetrated heavily into non-aerospace manufacturing with minimal or no penetration into aerospace manufacturing would be "first look" areas for robotic implementation opportunities. Data collected for Matrix 1 included: a description of the robotic application for the detailed application axis, relevance to aerospace applications, Air Force funding involvement, such as Manufacturing Technology (MANTECH) or Industrial Modernization Incentives Program (IMIP), and the names of the company, plant, point of contact, and source of information. Data for this matrix was collected primarily through an extensive literature search.

Matrix 2 - Current Implementation Opportunities Matrix

The purpose of Matrix 2 is to delineate the current robotic implementation opportunities in the aerospace industrial base, and to identify the impact of these implementations on the Air Force mission. This was done in two ways. When possible, implementation opportunities described by plant personnel were tied to Air Force weapon system production lines, so that the Air Force could assess the impact of the implementation on the procurement of those weapon systems. Second, information was collected concerning the projected effects of the implementation opportunity on the production schedules and costs. This report protects the company-proprietary data by presenting an aggregated view of the implementation opportunities, broken down not by specific weapon system affected but by generalized industrial base sector. Data categorized in Matrix 2 include, in addition to plant and contact name and address: plant processes suitable for current robotization (as categorized by the Detailed Application Axis), reasons why these processes are not roboticized, and the affect of robot implementations in these areas on cost, capacity, quality, and throughput flexibility (the ability to support surge and mobilization requirements).

Matrix 3 - Future Implementation Opportunities Matrix

The purpose of Matrix 3 is to project the future (1-5 year timeframe) robotic implementation opportunities in the aerospace industry. The information in Matrix 3 is similar to that in Matrix 2. However, information was gathered to determine the barriers to implementation, i.e., technological, financial, or time constraints. Where the barriers to implementation were identified as technological rather than cost or time, assessments were made as to whether the implementation was dependent on technology that was 1) in use somewhere in the robotics arena, 2) not in use in the robotics arena but available in other forms, or 3) not yet available.

2.2 Data Gathering Effort

Data acquisition effort for this task was performed in two parts: the first for the data in Matrix 1, baseline robotic implementations across industry, and the second for the data in Matrices 2 and 3, current and future aerospace robotic implementation opportunities. As Matrix 1 includes data from across the entire manufacturing industry, it was determined that the most efficient method of obtaining robotic implementation data would be through an extensive search of the current literature. Issues of a series of appropriate journals from 1984 to the present were scanned for descriptions of current robot implementations. In addition, the data gathering effort for Matrices 2 and 3 occasionally revealed current robotic implementations. These were included in the Matrix 1 data as aerospace implementations.

The primary means of data gathering for the second part of this effort to determine current and future robotic implementation opportunities was in the form of interviews with appropriate aerospace contractor personnel, i.e., persons at the plant manager level, when possible. A key element to this data gathering effort was ensuring that the level of data collected was consistent from one person and organization to another. This was facilitated by the development and use of a standard interview guide. The interview guide, shown in Appendix B, was designed to focus the answers of the respondents so that information would be compatible with the matrices, while allowing the flexibility to describe differing plant situations. While the majority of data gathering took the form of telephone interviews, a number of contractors were chosen for site visits. These site visits, performed by a major robot installer, provided the invaluable information necessary to analyze the transferability of technology from one factory floor to another.

2.3 Air Force Product Division Input

One of the primary goals of this report is to provide a document to guide the Air Force, at the Command, Product Division and SPO levels, in the implementation of robotic technology in the industrial base. To accomplish this, a guiding principle of the study had to be applicability to the Air Force and its supporting industrial base. To ensure the relevance of these study findings to the Air Force needs, all of the Air Force Systems Command Product Divisions participated in this effort and identified the members of the aerospace industrial base that should be included in this study. While the product divisions were not provided with a rigid set of criteria for selection, three factors appeared to underlay the selections:

- 1) the contractor is seen as a leader in technological innovation and can provide useful information
- 2) the contractor is seen as lagging in technological innovation and is a potential target for robotics, or
- 3) the contractor is so crucial to the support of systems that any benefits achieved at the contractor level produce direct benefits

at the system level. Factors affecting cruciality included supply bottlenecks, long leadtime parts, and critical technology parts.

These companies, listed in Appendix C, represent the baseline aerospace industrial base of concern to the Air Force.

2.4 Forecast Methodology

A forecast of robotic technology trends and expected advancements requires a recognition of the differences among current, near term and far term implementation opportunities. The key to the original forecast was the decomposition of a robotic system into components or discrete performance units, e.g., actuator, controller, end effector. This is the level at which most R&D effort is focused, and for which design and performance characteristics can be specified and projected. At this level of decomposition, it was possible to assess the amount of effort being put into advancing the performance of specific components. Furthermore, it was at the component level that it was possible to review journal articles and conference proceedings to determine the rate at which development was proceeding for each component. On this basis, component performance was projected, and the performance of a complete system was estimated. The results of this effort were then set against the technical constraints to the robotic implementation that had been identified to predict the growth potential of specific applications.

The forecast required for this report began by updating the Phase One forecast to reflect the advances in industrial robotics since the first forecast. Much of the new information was derived from robotics and manufacturing periodicals, with some coverage of conference proceedings to locate the leading edges of R&D. In addition, the data collected for this effort clarified the line between current technology (i.e., demonstrated and in-use) and near term opportunities (i.e., not yet ready for the shop floor). Direct communication with manufacturers was extremely valuable in updating this baseline.

The results of the technological forecast were compared to the opportunities described by the manufacturers. The results of this comparison were important because a contractor's view that certain technical barriers were insurmountable was often based on a lack of information of on-going R&D efforts. On the other hand, this comparison could also refute a contractor's belief that certain problems were minor and short term, when in fact either a lack of R&D effort in the area or a history of unpromising results dictated a more pessimistic outlook.

This approach has produced a refined characterization of time frame for the implementation opportunities presented in this report.

2.5 Prioritization of Information

One of the original goals of this effort was to present the identified robotic implementation opportunities in a prioritized format, i.e., identify a proposed order of implementation importance or urgency. To perform such a prioritization, a prioritization methodology was developed, which reflects the broad base of issues to be confronted when implementing robotic technology. Upon consideration of the methodology, it was concluded that it would be more beneficial to the users of this report to present the prioritization methodology without any specific results. In this way, biases would be eliminated and program personnel could perform individual prioritizations of the results which would reflect their specific areas of responsibility and points of concern.

To maximize the usefulness of this report to the program personnel, implementation opportunities presented in the following section must be assessed on the basis of fulfilling individual program needs and requirements. These needs and requirements, in terms of manufacturing capabilities, are expressed in two generic areas: reducing acquisition and life cycle costs and increasing the preparedness stature. Eight specific factors that aid in characterizing these areas are listed below. These eight characteristics, generic for all manufacturing processes, are:

1. Cost reduction
2. Quality enhancement
3. Throughput improvement
4. Technical feasibility
5. Ease of implementation
6. Application emulation
7. Reduction of skilled labor requirements
8. Required technical support level

These characteristics must be used to assess the application areas to determine the relative benefits of implementation to the Air Force.

Cost Reduction

Cost reduction factors should be assessed for each of the application areas selected. Major areas of concentration in cost reduction are as follows:

1. Reduction in direct manpower
2. Reduction in materials cost (usage)
3. Reduction of energy in utilities
4. Optimization of opportunity
5. Inventory carrying cost
6. Cost of quality

Of all cost reduction factors considered, direct manpower reduction is the most significant. In the aerospace manufacturing arena, direct labor represents as high as 35% of the total variable cost for the product. This cost element does not supercede material or manufacturing process cost; however, it should be noted that these costs are reasonably fixed when

considered within the confines of conventional manufacturing processes. For this reason, applications which successfully reduce direct labor required might receive a higher rating relative to other cost reduction areas.

Quality Enhancement

The cost of quality to any product or service can be significant. However, identifying the automation applications in terms of the potential impact on quality improvement can prove to be difficult. It is important to assess the positive quality enhancement of each specific application opportunity in light of the following parameters:

1. Reduction of rework
2. Improvement in manufacturing consistency
3. Reduction of scrap

Of the areas referenced, reduction of rework represents the most readily available opportunity to gage quality in a quantifiable manner. Furthermore, the most effective point of attack for reducing rework is through in-process inspection. The present manual inspection requirements and procedures can be enhanced through proper automation techniques. In general, inspection is a highly subjective task which requires a skilled operator to perform the specific inspection functions. Proper flexible automation of in-process testing will force a more timely inspection of products and prevent catastrophic failures through closed loop feedback.

For example, a manufacturing application which included prescribed inspection intervals and the addition of horsepower monitoring equipment to detect catastrophic tool failure would represent significant opportunities for overall quality improvement.

Each application candidate should be analyzed to discover appropriate quality improvement opportunities.

Throughput Improvement

One aspect of the utility of a robotic application is its ability to provide the user with a consistent throughput of production. For example, due to the vagaries of the manual machining operation, it is possible to experience throughput deviations in certain key applications. These deviations give rise to floor-to-floor timing constraints that are traditionally captured through the use of buffer storage material handling devices. A reduction of manufacturing bottlenecks will improve the overall throughput of production significantly, removing buffer storage completely in the ideal, "just-in-time" case.

Beyond the process methods which can be implemented to improve throughput, each automation application should be reviewed for potential requirements of the manual operation. In an effective automation work cell which utilizes robotic equipment or other flexible automation devices, it can be important

that a manual means of production also be provided. In this manner, the automation system itself will not be responsible directly for a lack of throughput consistency. Each automation opportunity will be analyzed to determine need of mechanical and control modifications to modify the application area for manual processing where required.

Technical Feasibility

Each selected application should be evaluated based upon technical feasibility. The technical feasibility should be judged based upon the following sub-points:

1. Analysis of similar applications which exist within industry
2. Review of technical documentation provided by professional societies for systems evaluation
3. Review of applications with an engineering design group to provide a value engineering assessment of feasibility

Ease of Implementation

Many of the potential logistical difficulties in the implementation of a robotics system stem from the system's ability to be integrated into an existing work area. Several factors influence the ease of implementing the robotics system. These areas are:

1. Difference in technology level between existing capital equipment and proposed robotics equipment
2. Skill level of direct operator personnel
3. Skill level of maintenance personnel
4. Robotics training programs
5. Degree of system "fine-tuning" required at vendor's site prior to full scale production

Of the five characteristics stated, characteristic number five has the greatest impact on the relative ease of implementation. Four types of automation systems are typically deployed in industry:

- A. New capital equipment procurement required for new process or replication of existing process
- B. Retrofit of existing capital equipment; capital equipment remains on-site

- C. Retrofit of existing capital equipment; capital equipment shipped to vendor site
- D. Stand alone; process-intensive application

The ease of implementation is positively impacted by conditions defined in items A, C and D above. System implementation is negatively impacted by conditions defined by item B above. Each application should be evaluated based upon potential impacts of each of these conditions.

The next most significant factor in the ease of implementation is factor 1, the difference in technology level between existing and proposed capital equipment. This factor is most important where there is a high degree of integration with older equipment, and plays a less critical role in independant installations and installations designed from the beginning for advanced automation. For the purposes of robotics implementation, seven levels of factory-floor technology can be defined:

- 1. Relay
- 2. Programmable controller
- 3. Analog control
- 4. Servo control
- 5. Closed loop process control
- 6. Network control

As a general rule, automation systems should be integrated slowly with respect to the increase in technology level required to support and maintain the system. Automation equipment which is designed to consist of a technology level that is significantly higher than the balance of capital equipment which will be located in the same work area leads to potential worker dissatisfaction and improper utilization of the automation equipment. Gradual integration of advanced technologies allows the work force to adapt to the new technology and fosters a higher degree of acceptance of the complete automation system. Companies that specialize in the installation of robotic equipment suggest that it is advisable with all automation equipment to increase the relative technology level by only one step per installation.

Application Emulation

An application assessment should be made to examine the emulation of proposed systems with existing systems in the field. This emulation should consist of technical work cell documentation which would provide the following:

- 1. Plan view layout of intended work area
- 2. Detailed depiction of capital equipment required for specific application
- 3. Graphic analysis of work volume and robot arm reach conditions
- 4. Graphic analysis of work flow

Each of the applications selected for analysis should be evaluated based upon their ease of implementation as discovered in the graphic analysis. The individual ratings for application emulation should be based upon prior learned experience in the installation and implementation of similar systems.

Reduction of Skilled Labor Requirement

An effective robotic system will reduce the amount of hands-on labor required to produce a given product. This reduction in skill level during production is due to the use of the robot control system to monitor and adjust process parameters. The amount of skill level which can be designed into a robot system, i.e., the amount of reduction in hands-on labor, is highly application dependent. Each application should be analyzed based upon present computer technology and the ease of implementation analysis previously generated to provide an optimum view of the potential for reducing skill level of required operators.

Required Technical Support Level

The skill level of maintenance and setup technicians required to support an automation system varies inversely with the skill level required for the manual operator. In general, the higher technology automation systems require less skill on the part of direct hands-on labor but require an increased skill level for maintenance and setup personnel. An analysis should be made for each application which will address the maintenance skill level technical capabilities which are required.

3.0 Baseline Industry Robotics Usage (Current Applications Matrix Output)

Due to the format of the data structures, matrix output can be presented in varying ways to highlight different topics. During the earlier phases of this study, information from Matrix 1 was organized to highlight the differences in current robotics usage between the aerospace and non-aerospace segments of the industrial base. This information was used as a guide for "first look" implementation opportunities in the aerospace sectors, i.e., if robotic spray painting was heavily implemented in the non-aerospace industrial base and not implemented in the aerospace sectors, it might be a promising implementation opportunity, barring any technology transfer difficulties. While it would have been desirable to catalog every robotic application in U.S. industry for Matrix 1, an effort of this magnitude would have been beyond the scope of this study. It was decided that a statistically meaningful number of implementations would be sufficient to provide an adequate characterization of the baseline of robotics usage in industry while remaining within the scope of this study. The selection of robotic implementations to be included in Matrix 1 was based on the current literature. Only those applications reported in the literature within the previous year were included. These totaled approximately two hundred robotic applications.

While this method of selection proved adequate to scale the effort, it did introduce a bias into the data gathering effort. By nature, those applications reported in the current literature are generally technologically advanced, i.e., on the leading edge of R&D. The data gathered from the literature reflects this, and there is a disproportionately small number of very basic, simple robotic applications represented in Matrix 1. Forging and casting, for example, were among the first robotic applications in the U.S., and because they are well understood have all but disappeared from the literature. This bias was compensated for in the analysis of the data by taking into account data from less recent sources.

During the latter phases of this study, the information in Matrix 1 was organized to give a profile of the current robotic implementation status of each of the aerospace industrial base sectors. In this way, differences in robotic utilization between aerospace sectors could be highlighted. This organization provided a more directed view of possible implementation opportunities within each of the individual sectors.

Presented below is the composite output of Matrix 1, showing the differences in the status of current robotic implementations between the aerospace and non-aerospace industrial base. It should be noted that the relative number of aerospace and non-aerospace applications do not imply any conclusions regarding the extent of robotic implementation among the industry base. These numbers only reflect the reported implementations, and were used to highlight areas of implementation, not quantify them. An alternate organization of Matrix 1 information, highlighting the differences in implementation status between the individual aerospace sectors, is presented in Section 4.0 along with the implementation opportunities.

COMPOSITE MATRIX 1 OUTPUT

Recently Reported Robotic Applications

Appl. Axis Task Code	Description	Aerospace	Commercial
1.1	Arc Welding	2	6
1.2	Spot Welding	1	2
2.1	Surface Inspection	5	4
2.2	Internal Inspection	6	1
2.3	Functionality Test	0	2
3.1	Open Tol. Assembly	4	5
3.2	Close Tol. Assembly	11	13
3.3	Fastener Assembly	4	2
4.1	Paint Application	1	6
4.2	Surface Coating	2	2
4.3	Other Coating	0	1
5.1	Mechanical Bonding	0	3
5.2	Assembly Bonding	0	2
5.3	Sealant Application	0	2
6.1	Grind/Deburr	3	1
6.2	Coating Removal	0	1
7.1	Machining	21	3
8.1	Metal Casting	0	5
8.2	Plastic Molding	0	1
9.1	Aluminum Forging	2	0
9.2	Other Forging	1	0
10.1	Material Handling	6	11
10.2	Special Mat'l Handling	6	9

4.0 Implementation Opportunities by Sector (Matrix Two and Three Output)

The results of this implementation opportunity assessment and forecast are presented here by industrial base sector. The industrial base sectors are those defined in the 1984 Air Force Production Base Analysis (PBA): Aircraft, Armament, Ballistic Missile, Electronics, Propulsion, and Space sectors. These aerospace industrial base sectors have an approximate correlation with the Product Divisions of the Air Force Systems Command, and are defined as that portion of the aerospace industrial base supporting each of the product divisions, i.e., the electronics sector is that part of industry supporting the Electronic Systems Division (ESD), the aircraft sector is that part of industry supporting the Aeronautical Systems Division (ASD), and so forth. The purpose of this method of data presentation is to focus the identified robotic implementation opportunities to specific Air Force interests. In this way, those personnel involved in or having oversight for modernization efforts can easily focus on robotization candidates that relate to the manufacturing processes specific to their needs.

It is important to stress that there is a significant overlap of manufacturing functions and processes among the aerospace industrial base sectors. For example, the large scale spray painting and coating performed in the Aircraft sector is functionally the same as that required in the Ballistic Missile sector. Additionally, electronics products permeate all of the industrial sectors: avionics in the Aircraft sector, guidance and control units in the Ballistic Missile and Armament sectors, communication and control systems in the Space sector, and control systems in the Propulsion sector. In an effort to avoid redundancy, detailed descriptions of application opportunities are presented only in the industrial base sectors to which they are the most applicable. For completeness, however, references to these descriptions will appear in all sectors to which the application is applicable.

To provide a unified view of the robotics implementation opportunities within each industrial base sector, the information from all matrices are presented together. Thus, for each sector, there is a short listing of the current implementation status, current implementation opportunities, and future implementation opportunities. For the purposes of this study future opportunities are those which will become suitable in the one to five year time frame, on the basis of emerging technology. This is in contrast to current opportunities, for which the necessary technology is already available. Additionally, any inappropriate implementations discovered during the study will be discussed.

Included in each sector are in-depth studies of one or two hypothetical high priority implementation opportunities, both current and future. These studies are presented for illustrative purposes, and describe representative examples of the possible implementation opportunities. These examples will be set off from the main body of the text by indentations.

All robotic implementations are preceded by a code which refers to the position of the application on the Detailed Application Axis (Appendix A).

4.1 AIRCRAFT SECTOR

A. Current Implementations:

- 1.1.2 Tungsten Inert Gas (TIG) welding
- 2.2.1 Ultrasonic Testing of Aircraft Panels
- 3.0 Assembly
- 3.3.1 Riveting Small Subassemblies
- 3.3.1 Riveting Large Skin Panels
- 4.1 Painting
- 4.2 Plasma Arc Metal Spraying
- 6.1 Grind/Deburr
- 7.1.3 Drill, Countersink
- 7.1.6.3 Water Jet Cutting of Kevlar

B. Current Opportunities:

1.1.1/2 Metal Inert Gas (MIG)/Tungsten Inert Gas (TIG) Welding

MIG/TIG welding is used on structures where smooth joints are required. These joints are able to maintain their integrity under the high temperatures and repeated thermal cycling common to aircraft. Robotic welding has been used very successfully throughout industry, and represents a significant opportunity for increasing the quality and decreasing the cost of many of the welding functions performed in this industry sector.

2.1 Gaging

The extreme precision requirements which permeate the aerospace industry dictate frequent and critical part measurements. Automated systems allow in-process gaging and measuring, which have the capability of rejecting out-of tolerance parts early in the work flow. As an example, in-process gaging can be used to check tolerances to 1/10 mil.

2.2 Wing Section Inspection

Current developmental systems allow ultrasonic inspection of aircraft skin sections, as well as N-ray and X-ray inspection of entire sections, via an overhead gantry robot. As these systems are perfected, one hundred percent inspection of critical parts could become very reliable and cost-effective. Furthermore, these applications would have the advantage of removing humans from an environment that is potentially hazardous.

4.1 Spray Painting

Robotic spray painting is a mature technology, and has been in use for several decades in places such as the automobile industry. The applicability to the aerospace industry is two-fold: painting small parts and painting large structures. Robotic painting of small parts, such as subassembly components, generally involves a stationary robot, with the part moving on an automated conveyor or part presentation device. Robotic painting of

large structures such as entire airframes, is a less mature technology, and would involve a mobile robot performing the paint operation while the structure remains stationary. This type of function would be applicable to the aircraft final paint process.

6.1 Plastic Grind/Deburr/Edge Curl Ending

The drive for lighter aircraft has caused an increased use of high strength, low weight plastics in the aerospace industry. These materials must be machined and finished in ways similar to metal counterparts, but can be more susceptible to deformation from heat and stress. Robotic machining operations would increase the consistency of the manufacturing process, thus decreasing the part to part variations due to deformation.

7.1.1/2/3 Milling, Routing Drilling

Due to the large number of precision surfaces in aircraft, there is a significant amount of metal forming and joining. Operations such as milling, routing and drilling, currently performed for the most part by manual methods, represent a great opportunity for robotization. As the range of tolerances varies greatly, some implementations will be more difficult than others. Robotic drilling and routing with templates is a mature process, and is in use in the aerospace industry. Sensor-based, high precision robotic machining is less mature, being currently under development.

7.1.6.2 Laser Cutting

Industrial lasers are currently in use to cut a wide variety of materials. Many of the materials used in the aircraft sector are candidates for laser cutting, and robotic laser cutting would allow very efficient part change-over, as required in the small batch environment of the aerospace industry.

7.1.6.3 Water Jet Cutting

The development of water jet and abrasive water jet cutting technologies has opened a broad range of robotic implementation opportunities. Materials from fabrics to phenolics to thin aluminum sheet stock are cut successfully with water jets, with the advantage of the elimination of heat and fire hazards that are present in other cutting methods. This type of implementation, in which the robot holds the cutting tool, generally would require little advanced technology sensors, and would be a straightforward implementation.

8.1 Aluminum Structural Castings

Robotics usage in non-aerospace casting has resulted in major benefits, largely in the area of consistency. Aerospace aluminum castings should also be able to achieve these benefits, especially for investment casting. Investment cast parts are only as good as their mold, and the mold quality is crucially dependant on the controlled sequence of slurry and sand application. The consistency of robotic systems has produced major benefits for non-aerospace investment casting, and should be directly transferrable.

8.2 Plastic Molding

The increasing use of high performance plastics in aerospace systems is opening up opportunities to transfer the well developed commercial technology of robotic-assisted injection molding to aerospace. Most of the problems in this application (e.g., handling still warm parts, detection of incomplete part removal) have already been solved in the commercial environment.

9.2 Hot Die Forming

Hot die forming is another of the implementations thoroughly established in commercial practice, and as use of this forming technique by aerospace increases, this commercial background should be consulted to determine the appropriate level of automation and robotics for aerospace implementations.

9.2.10 Tube Bending

The requirements for tube shaping in aerospace manufacturing is very high, for everything from low pressure gas lines to high pressure hydraulic lines. Successful tube bending is a demanding process involving a controlled combination of drawing and cold flowing, with precise and delicate control required to avoid kinking or flawed sections. Robotic systems using adaptive control can bring this precision and delicacy into a consistent automated process.

10.1 Palletizing

Palletization, one of the most wide-spread uses of robotics, is generally most applicable in high volume operations. While the aerospace industry generally produces low volumes of final products, components and subassemblies can be produced in quantities large enough to make robotic palletization cost-effective.

Representative Application Example:

MIG/TIG Welding of Aircraft Engine Exhaust Manifold and Ductwork

Engine exhaust manifold and ductwork is fabricated from stainless steel and other high strength steel alloys in complex shapes to achieve proper fluid flow of exhaust gases and other by-products. In general, present manual fixtures do not provide positive registration of components with reference to finished part specifications. Fixturing adjustment is usually provided manually through the use of highly adjustable toggle-style and brand-style clamping mechanisms. Most weld path routines, selection of weld schedules, part fitup and alignment and part registration are manual in nature.

A freestanding, articulated robot equipped with appropriate

turntable and fixture devices can be utilized to eliminate the need for up to three manual welding booths for this type of application. The automated system can be supplied to provide both MIG and TIG welding functions in a continuous, automatic operation. Weld programming and fixture design can be extensive, however, the long-term benefit is improved production throughput, improved quality of welding and a significantly enhanced defense-readiness posture. Due to the complex nature of both MIG and TIG welding of this type of material, the skill level required for successful execution of this application is significant. The skilled labor quotient for this type of application can be significantly reduced through the use of the automation system specified.

C. Future Opportunities:

2.1 Drill Hole Location and Inspection

Usually performed as an in-process function, this operation is used to detect out of tolerance conditions. While current technologies allow detection, future technologies will enable in-process, adaptive path control for the robot to either re-drill or alter the position of the fastener.

3.1 Canopy Assembly

There is currently a project to develop an operational robotic cell to aid in the assembly of aircraft canopy systems.

3.1 Wire Harness Assembly

Although the aircraft sector uses wire harnesses to integrate electronics systems on board aircraft, their production is an electronics sector function and is described in detail in the electronics sector portion of this chapter.

3.3.1 Riveting

This opportunity is as described in the current opportunities, with the addition of adaptive path control and decision-process capabilities. Future robotic systems will be able to choose fastener type on the basis of hole characteristic without manual input.

4.1 Depainting

Technologically similar to painting, depainting will require the additional capabilities of advanced sensors and adaptive process control to monitor the effect of the removal process on the part. Depainting operations may also require more robust systems due to the abraisive nature of the materials used.

5.3 Sealing of Wing Surfaces

Embedding fuel tanks in wing structures requires that the interior wing surfaces be adequately sealed. Currently, this is a very difficult operation requiring a high degree of dexterity to maneuver in a constricted and chemically noxious environment. This represents an excellent opportunity for a robotic coating application. While it would be possible to perform this process with currently available closed-loop servo technology, advanced sensors and adaptive path control will make the application more technologically feasible.

6.1 Grind/Deburr

Robotic grind/deburr of sheet stock, castings, forgings and plastics, as described under current opportunities, can be enhanced with advancing technology. While some of the more critical tolerances are currently beyond the range of current robotic technology, future technology will be able to process the materials to the required tolerances. Furthermore, increased process monitoring can allow the safe and consistent operating of grinders and deburrers at the most efficient level of loading.

6.4.2 Contour Roll Forming

The advantage of a robotically assisted contour roll form operation, as with any other metal forming, is the removal of personnel from a potentially hazardous environment. Additionally, depending on the size of the initial and finished parts, the robot would eliminate worker fatigue resulting from frequent handling of heavy parts.

6.5 Canopy Polishing

The mechanical technologies necessary for robotic polishing are available; however, canopy polishing will require advanced control and sensing systems. The control system will be required to start and stop polishing on the basis of the comparison of optical sensor feedback to pre-set clarity criteria.

7.1 Machining/Routing

As in the grind/deburr operations, these functions are currently available but will increase in capability as advances in sensor and control technology occur. For example, very precise robotic machining currently requires some type of pre-finishing to ensure that the part is within a given specification. Future robotic machining will allow a "raw" part to be taken through all finishing steps to the final product.

10.2.6.1 Composite Filament Winding

Successful filament winding over non-cylindrical forms requires precise control of the filament with respect to position, tension and direction of tension. While robotic systems can provide precise control over these parameters, determination of the required values is a different, and more complex problem. The most efficient utilization of robotic systems for

this application will occur when a Computer Aided Design (CAD) system can integrate a model of the shape required with the mathematical analysis to determine the most effective winding plan. The robotic system would then convert this plan directly into the required robot control sequence.

10.2.6.2 Automated Tape Layup

The increased use of composite materials in current aerospace weapon systems is driving a rapid advance in the production methods for composite materials. There has been a significant amount of research performed in the area of robotic handling of fabric-type materials. As this work begins to result in useful, predictable methods of fabric material handling, both automated tape and composite ply layup will experience a significant increase in usage.

Representative Application Examples:

Riveting - Small Structures

A wide variety of automation/cost reduction opportunities exist in the small structure riveting area. In every case, the introduction of Class A fixturing and flexible automation devices for providing drilling and routing functions can greatly reduce costs and improve overall throughput.

For the purpose of this analysis, two areas have been isolated for further automation discussion. It should be noted that a wide variety of systems opportunities exist in the small structure area. The selected examples represent optimum opportunities for significant return on investment for capital equipment.

The two specific small structure riveting opportunities are:

1. Small bulkhead assembly
2. Landing gear door

Each of these opportunities will be addressed separately.

Small Bulkhead Assembly

The small bulkheads required for compartment separation and structural support for aircraft are generally produced in a series of portable, manual fixtures. Each of the bulkhead assemblies requires a significant amount of hand drilling, milling and fastener operations. These operations are tedious in nature and require a significant amount of skilled labor input to produce an acceptable finished product.

A suggested automation system would consist of a two position shuttle transfer device, equipped with a robot on either side of the shuttle. The robots will be equipped with multiple end effector tools to provide synchronous drilling, countersinking, milling and rivet fastening operations. Rivets will be supplied to the robot system utilizing a vibratory feeder bowl equipped with appropriate escapement devices. The two robots will operate simultaneously on a bulkhead fixture to provide 90% of the drilling, milling and rivet fastening operations. Huck bolts and other threaded fasteners will continue to be applied by manual methods. The manual operator will be required to setup one of two input stations and to provide for initial location of members to be drilled. The existing fixturing will be modified to provide a Class A capability for initial part loading. Initial part locator fixture blocks will be designated to cam out of position for the purpose of robot clearance during automated cycles.

Landing Gear Door Assembly

The landing gear doors for a particular type of aircraft are produced two at a time, in separate asynchronous operations, in a small structures riveting area. These landing gear door require a significant amount of external skin drilling. In addition, the outside edge must be routed to provide proper fitup and seal of the door during final assembly.

The automatic concept will consist of an overhead gantry robot which will be designed for a multiplicity of tools and perform all drilling, countersinking and milling operations required for the product. A two position shuttle system will be utilized to handle the work piece through the manufacturing process. A series of shot pin locators will be provided to accurately affix the landing gear door. The operator will be required to perform load and unload functions only. All secondary riveting functions will be performed on an appropriate dedicated riveting machine.

The system will be designed as a freestanding device which is capable of handling a variety of door products.

Representative Application Example:

Primary Finish - Canopies

High strength, impact resistant canopies for sophisticated weapon systems can be accurately polished to a final condition utilizing robotic automation. The basic system would consist of the following elements:

1. Input and output handling bucks

2. Interchangeable canopy fixtures and locating devices
3. Centralized material handling system - griddle operated
4. Two optical selectivity cells
5. Multiple axis, free standing articulated robot equipped with tactile feedback control
6. Polishing tool and magazine - with self locating nest feature

During the manufacture of weapon systems canopies, most notably for airframe systems such as F-16 and F-15, the optical clarity and drill characteristics of the canopy are extremely close in tolerance. Absolute optical verification is required for both pilot sight characteristics as well as the satisfactory interface of inboard optical devices utilized for navigation and weapons sighting.

Due to the nature of the forming process of the canopy, stress lines, pock marks, longitudinal scratches and other types of abrasive flaws are produced in the exterior and interior surfaces of the canopy. Manual operation requires a significant amount of skilled labor to remove defects by polishing to achieve the appropriate optical characteristics. This application is ideally suited to the use of a backlighted vision system as equipped with appropriate computer control of the polishing process. Interchangeable tools can be utilized to custom blend and polish each individual canopy. While this is certainly a batch manufacturing opportunity of one part per batch, the obvious positive impact to overall quality and throughput is significant.

4.2 ARMAMENT SECTOR

A. Current Implementations:

- 2.2.2 X-Ray Inspection of Projectiles
- 4.2.7 Liquid Solder Application (Tinning)
- 10.0 Various Material Handling Tasks

B. Current Opportunities:

1.3 Laser Welding

Armament application in laser welding are based on the ability of laser welding to minimize and control the Heat Affected Zone (HAZ). This reduces the degradation of material performance from thermal effects, and provides more predictable material characteristics in the vicinity of the weld.

3.1 Subassembly Installation

Robotic installation of subassemblies has potential for implementations at the prime contractor level, especially for guided missiles. With make/buy ratios commonly less than 40%, prime contractors are largely assemblers and testers of subsystems. The concentration of subassembly handling and installation in this area provides a great potential for robotic implementation at the prime contractor level, and the level of communication within the guided missile community should assist robotic implementations into this area.

3.2 Complex Small Part Assembly/Printed Circuit Board Assembly

The advantages of robotics for assembly activities are essentially the same as those described under the electronics sector. However, due to the increasingly complex nature of current armament products, and their growing dependence on electronic subsystems, many respondents in the Armament sector specifically mentioned robotic implementation opportunities in circuit board assembly. For this reason, a detailed example of this opportunity is presented at the end of this section.

4.2.7 Spray Coating - (Other Material Coating)

Armament applications for specialty spray coating are largely the same as for Space and Aircraft. The notable difference is the product quantity advantage; i.e., the DoD generally acquires significantly greater numbers of armament items each year than space vehicles and aircraft. While painting a single C-5 aircraft may cover as much square footage as painting ten thousand AIM-9 Sidewinder missiles, with respect to automating the process the crucial figures are one aircraft versus ten thousand missiles to paint. This greater number of repetitions can speed up payback of investment, and, as a result, Armament implementations could be leading the way for other sectors.

10.1.6 Material Handling

The advantages of using robotics in material handling applications are described in detail in the Aircraft and Propulsion Sectors. Two specific implementation opportunities identified by respondents in the armament sector were box loading (palletizing) and final component packaging.

10.2.4 Material Handling of Explosives

Robotic material handling can add safety to many of the operations that involve moving or other manipulation of explosive materials. The consistency of handling and the ability to maintain an explosion proof environment reduce the risk of accidents, while the removal of personnel from the immediate vicinity reduces the hazard level in case of an accident. While robotic technology suitable for these applications exists, in many cases there has been a delay in governmental approval for use of the technology in these applications.

Representative Application Example:

Automated Circuit Board Assembly

An application that has potential implementation opportunities DOD-wide is automated circuit board assembly. With the exception of wire harnesses, the automated circuit board assembly applications may represent the greatest application challenge to robots within the aerospace community.

Recent improvements in manufacturing process control technologies and industrial robot capabilities allowed certain manufacturers in the private sector to enjoy the benefits of full or semi-automated board assembly systems. It should be noted, however, that the majority of these opportunities involve higher production quantities than are typical in the aerospace community.

A representative Aerospace prototype system might consist of the following elements:

1. A centralized material transfer system that transports the circuit boards through a sequential set of fabrication steps.
2. A precomponent insertion kitting system for collating and assemblage of insert packages.
3. Various types of material handling devices, feeders, and input systems to transport axial, radial, flat pack and miscellaneous electronic componentry to the work area.
4. Vision and other inspection stations positioned

at strategic points through the process to provide for 100% in-process inspection.

5. Lead preparation stations for lead straighten, cutoff, pre-tin, crimp and clench functions.
6. A series of free standing multi-axis robots equipped with the adaptive control necessary for both insertion detection and modification of trajectory.
7. Material handling tray packs for both input and output board assembly.
8. Centralized adhesive application system for bonding of specific electronic components to printed circuit board surface.
9. Automatic flow soldering system with cooling cabinet.
10. Material handling for final packing and shipping.

Several recent advances in printed circuit board assembly have included the use of surface mount techniques for a wide variety of consumer product circuit boards. As the surface mount technologies improve, the economies of scale will also provide attractive alternatives to normal leaded component insertion manufacturing techniques. Surface mount technology yields boards of greater component density and lower overall unit weight than standard techniques. Coupled with this weight and size reduction is the improvement in overall electrical characteristics and board performance in the field.

Several limitations exist in applying surface mount technology to aerospace weapon systems printed circuit boards. Surface mount technology requires a significant amount of process control, which can be difficult to automate in a batch environment. However, some of these processes have been refined and are employed in a controllable environment where industrial robots could be utilized for such tasks as applying adhesive materials, applying bonding and grout materials, placing components on boards and transporting board assemblies to and from process stations. This is one area in particular where, due to limitations of technology transfer, many companies are working to solve problems of automation that have already been solved by other companies.

Both circuit board construction processes are amenable to the use of robots and other flexible automation devices for the assembly of aerospace-quality electronic boards.

C. Future Opportunities:

1.0 Welding

The future implementation opportunities for welding in the armament sector are similar to those in the aircraft sector. As sensor and control technologies advance, more demanding and complex weld applications will become suitable for robotic welding. For example, advanced process sensors, such as IR and visible light vision, along with more complex adaptive control algorithms, will allow robotic welding implementations to compensate for greater ranges of part inconsistency and fit-up.

3.1 Final Assembly of Explosive Units

These implementations will be similar to, but extensions of, the current implementation opportunities. While there may not be radically new opportunities developing, the future opportunities will take advantage of newer technology to perform assembly functions currently out of range of robotic capabilities, such as high precision fuze assembly and handling and final packaging of submunitions. Additionally, developments in actuator technologies and advanced materials for robot manipulators will enable a wider variety of robots to be approved for use in explosive/flammable material environments.

10.2.4 Material Handling of Explosives

As discussed above, advances in actuator technology and manipulator materials will enable a broader range of robot configurations to be approved for use in an explosive material environment. The final goal of automated explosive material handling would be the total removal of personnel from the explosive environment.

4.3 BALLISTIC MISSILE SECTOR

The Ballistic Missile sector produces a very limited number of products, each having a great level of both mechanical and electronic complexity. In general, robotic technology is not well suited for this type of production. Because of the electronic complexity of the products, however, there does exist a significant opportunity for robotics implementation to support the electronics used within the Ballistic Missile sector. Since this production is categorized under the Electronics sector, detailed descriptions of the implementation opportunities for space electronics products are presented as Electronic opportunities.

A. Current Implementations:

- 3.1 Assemble Brackets
- 3.3.1 Rivet/Derivet
- 5.0 Spray Adhesives

B. Current Opportunities:

7.1.1/2/3 Milling/Routing/Drilling

The opportunities for implementing robotics in these applications are essentially the same as those described under the aircraft sector, especially in the preparation of large sheet stock. For this reason, an airframe routing opportunity is presented as the representative application example for this section.

Representative Application Example:

Routing

A current airframe manufacturer uses a series of five pantograph routers to finish a wide variety of flat stock products. The pantograph approach is utilized to provide manual flexibility to route a wide variety of different products, ranging in overall rectangular size and thickness. The pantograph approach utilizes a model which is traced for each of the operations. A significant amount of learned operator skill is required to properly route products required in the construction of the airframe products.

An automated system could be provided which would eliminate the pantograph process and replace it with a freestanding programmable robotic solution. The robot would be mounted on a common steel platform which would be equipped with a two-position dial index table.

All routed shapes would be pre-programmed utilizing an NC-style control system for the robot. Part programs could be generated offsite, utilizing a CAD system, or generated onsite, utilizing MDI capabilities.

C. Future Opportunities:

3.1 Final Assembly - Explosive Units

Robotics can be implemented in these applications for the same reasons given under handling explosives in the armament sector, i.e., reduced risk of accident and reduced hazard to personnel.

7.1 Machining Rocket Motor Casings

There is a potential for robotic implementations in both major techniques for producing rocket motor casings: machining metal and building up composites. For large rockets, the machining approach is typical, and not very different from non-aerospace, high precision machining. The low volume, however, works against cost-effectiveness for expensive capital equipment.

10.2.4 Material Handling - Explosive Units

The advantages of using robotics in these applications have been described fully in the armament sector.

10.2.6 Composite Assembly

As with the Aircraft and Armament sectors, the use of composite materials in the Ballistic Missile sector will continue to grow. The most common application for composites will continue to be in the Airframe of the ballistic missiles. Two types of fabrication are relevant to these applications: automated filament winding for smaller diameter sections and automated tape and ply layup for the larger diameter sections.

Representative Application Example:

Composite Layup

The increasing use of composite materials in the aerospace industry, and specifically the missile-producing sectors, has prompted research into the improvement of manufacturing methods of constructing composite segments. Industrial robots can be employed to perform the following major tasks in the area of composite fabrication:

1. Fabrication of carbon, boron and graphite epoxy sheet (cloth handling, curing laying up, etc.)
2. Adhesive and resin bonding of composite layers (material handling in and out of curing ovens, etc.)
3. Material reduction or removal (drilling, routing, grinding, etc.)
4. Assembly of composite sections (riveting, other fastening, etc.)
5. Material handling of complete composite sections

4.4 ELECTRONICS SECTOR

A. Current Implementations:

- 1.0 Welding
- 1.2 Spot Welding
- 3.1 Assembly
- 3.2 Circuit Board Assembly, Including:
 - Wire Stripping
 - Wire and Component Tinning
 - PCB Component Insertion
 - PCB Wave Soldering
- 3.1 Cable Harness Assembly
- 3.2 Wire Bonding Integrated Circuits
- 4.1 Circuit Board Masking
- 10.1.6 Component Kitting

B. Current Opportunities:

1.0 Welding

Welding in electronics applications breaks down into two areas: structural parts and electronic components. For structural parts, the robotic applications have the same potential as for any other small mechanical systems. For electronic components, welding is used for case forming and lead attachment. In the case of lead attachment the robotic advantage is predictable electrical and mechanical joint quality, with predictable heat input.

2.3 Discrete Component Test

High reliability systems require multiple levels of testing of components. Incoming inspection is virtually universal, with testing after trimming, tinning, and lead bending being incorporated to varying degrees. The speed of robotic systems as well as the ease of insertion in an automated parts flow has potential for raising the percentage of parts inspected to the ideal 100%. 100% inspection of parts can be an aid in increasing the overall reliability of the total system.

2.3 Circuit Board Test

For testing of circuit paths, robotic positioning of probes allows the rapid verification of foil path continuity. The robotic advantage is speed and the ability to switch from one known board layout to another essentially instantaneously. For testing of circuit function, robotic systems allow fast and precise probe placement for readings and signal injection.

3.1 Cable Harness Assembly

In this type of application a robot would perform the labor intensive pegboard work. A detailed application example is presented at the end of this section.

3.1 Small Electronic Subassembly

Robotic advantages in this application are the same as other assembly applications, e.g., reduction of skilled labor needs and a reduction of defective assembly rate. Electronic subassembly includes component assembly, such as potentiometers and cable connectors, as well as subsystem assembly, including complete chassis assembly.

3.1 Wire Wrap

Wire wrap connections are based on wrapping connecting wire around a standard sized square post, generating a pressure weld between the wire and the post corners. Robotic wiring of wire wrap boards should be rapid to implement because the problem breaks down into two manageable pieces: precision positioning in x-y coordinates and a specified number of turns of the wrapping head while controlling the drag on the wire feed. Both of these are within reach of robotic technology; the barriers are ease of set-up and programming. Displacement errors, (i.e., wire routed to the wrong post) are common, and fault finding on wire wrap boards can be very difficult. The benefits of a robotic wire wrapping station would largely result from reduced rework.

4.2 Soldering

Point soldering of electronic components which, for various reasons, cannot be wave soldered is a demanding task. A skilled operator observes the action of both flux and solder in order to control the quality of the joint. The barrier to robotic point soldering is the difficulty in incorporating subtle visual (or other sensory) input into adaptive control.

5.3 Adhesive Coating of PCB Components

Adhesives are used for Surface Mounted Devices (SMDs), either as a permanent bond or to hold component prior to wave soldering. Non-SMDs also use adhesives to provide mechanical mounting for components like inductors and electrolytic capacitors so that solder joints do not support the component. Robotic technology has been used successfully throughout industry for various adhesive application tasks, and would greatly enhance the consistency and quality of adhesive application for electronics.

10.0 Various Material Handling Tasks

The potential opportunities for robotic material handling within the electronics sector exist at many levels. Electronic assembly is a very part-intensive process, and the movement of many different types of parts must be coordinated throughout the assembly process, all the way from incoming part inspection to part kitting to final packaging. Robotic technology represents a great opportunity to automate these material handling tasks.

Representative Application Example:

Wire Harness Assembly

A wide variety of wire harness assemblies are produced. They are categorized, for the purpose of this report, into small and large harness varieties for descriptive purposes only. "Small" wire harness are categorized as those harnesses connecting subsystems within a system, e.g., jumper harnesses from one PC board to another. Small harnesses usually do not have elaborate terminal connectors. "Large" wire harnesses are those harnesses used to connect one system to another, such as the data communications bus for the airframe avionics. Large harnesses generally have specialty terminal connectors.

Small Wire Harness Assembly

The small harness assemblies which are considered for automation presently require a significant amount of manual labor to arrange the pegboard plotting diagram, layup the cut and terminated wires, bundle the wire harness and prepare for assembly.

A self-contained overhead gantry-style robotic device can be utilized to transport the cut-to-length wire from a spool feeder through an automatic marking system and subsequently through the sequence of routing pegs. The system can be equipped for automatic tie wrapping and continuity verification. Initial systems could be specified for straight run wire harnesses which represent a small but significant fraction of overall wire harness products used in aircraft.

Large Wire Harness Assembly

Longer and more elaborate wire harnesses are required for a wide variety of communication and control functions for many aircraft. The large wire harness assemblies are produced in the same fashion as the small wire harness with the exception of the addition of a wide range of specialty harness connectors and the provision for wider harness layout area.

Both of these robotic implementations have a high priority due to the high probability of success. Through an Air Force funded program, a defense contractor has developed and demonstrated the Robotically Enabled Assembly of Cables and Harnesses (REACH) system. These technology could be transferred to other contractors as needed.

C. Future Opportunities:

2.3 Circuit Function Test

As described above, this implementation opportunity is currently possible. However, with advances in sensor technology this opportunity will become available to a much broader range of products. For example, the current method of robotically aided circuit function test is to have the robot place the circuit card into a dedicated test jig. There is currently under development, however, a robot arm with built-in circuit function capabilities. With these capabilities, the robot can be testing the circuit card while transporting it from one step in the manufacturing process to another, thus greatly reducing test time.

3.0 Assembly

As robotic and sensor technologies advance, those assembly tasks that are not possible with current technology, due either to complexity or tolerances, will become possible. Two especially significant assembly opportunities are circuit board stuffing and hybrid assembly.

3.2 Circuit Board Stuffing

Current "semi-automated" board stuffing (a person presented with pre-kitted parts in the correct order and guided to the correct board location by a projected light) has potential for replacement by robotics. The use of kitted parts and precise location of the board in a fixture saves having to solve these problems for a robot, and a robotic system may be cost effective due to reprogrammability in applications where hard automation is too expensive for the volume.

3.2 Hybrid Circuit Assembly

Hybrid circuits require precision assembly under controlled environmental conditions, operating on a scale that is literally "microscopic". The suitability of robotics in this application is enhanced by the hardware intensive and costly nature of a hybrid work station, and the relatively low first-pass yields being achieved by current manual set-ups.

4.1 Circuit Board Masking

As tolerances for PC board foil patterns increase to the 5 mil or less spacing level, the demands for precision of the mask and resist layers applied during the fabrication process increases. In these applications, increased consistency of application is related to increased batch quality. Robotic technology, because of its high level of consistency, can be an important factor in improving the quality of the PC board fabrication process through consistency of masking application. Additionally, these same capabilities can be used to increase the consistency of the masking applied prior to wave soldering.

4.5 PROPULSION SECTOR

A. Current Implementations:

- 2.2.2 Turbine Blade Inspection
- 4.2 Thermal Spray Coating
- 6.4.3 Heat Treating of Disks
- 7.1.1 Sonic Machining of Disks
- 9.0 Isothermal Forging
- 10.1 Part Washing
- 10.1.7 Composite Manufacturing

B. Current Opportunities:

1.0 Welding of Final Assemblies/Small Part Subassemblies

Welding of final assemblies and small part subassemblies in the propulsion sector is similar to that in the aircraft sector. Descriptions of these functions, as well as detailed application examples have been presented in the previous section. An additional welding implementation opportunity exists in the propulsion sector, however. During engine repair, robots have been used to apply weld material to build up turbine blade surfaces for regrinding and refinishing.

2.2.2 Turbine Blade Inspection

A sophisticated system for robotic X-ray inspection of turbine blades has been demonstrated. This system, developed under an Air Force funded program, can be adapted for use in similar and related applications.

4.2 Thermal Spraying

Robotic thermal spraying can be used to replace conventional thermal spraying tasks performed on engine components. Thermal spraying is a good implementation opportunity because it removes humans from the heat, optical glare and environmental hazards from the thermal spray environment. Advanced methods of robotizing and automating the process will increase productivity, improve operator environment, improve product quality and reduce the cost of the parts.

7.1 Disk and Turbine Air Foil Finishing

The high volume of disk and airfoils necessary for each aircraft engine make the finishing operations for these products, grinding, deburring, etc., prime candidates for robotic implementation. Robotic grinding and deburring implementations have been previously described in the Aircraft Sector part of this chapter.

8.1.3 Investment Casting

The propulsion sector of the aerospace industry is characterized by a

significant amount of investment casting, primarily of blades and airfoils. As described in the aircraft sector, robotics can play a very beneficial role in investment casting.

10.1.7 Composite Manufacturing

The growing need for composites in aircraft has dictated as much as a three to four fold increase in composite usage in some aerospace manufacturers. While composite materials are generally not widely considered for use within the aircraft engine itself, many supporting structures such as cowlings and ductwork may be good candidates for composite materials. For the production of these parts, robotics can be used to aid such functions as lay-up and transport. A more detailed description of robotic composite handling has been presented in the representative application example for the Ballistic Missile sector.

C. Future Opportunities:

2.2.2 Turbine Blade Inspection

As the sensor technology advances, the turbine blade inspection system described above will be able to be modified to increase resolution and handle a greater variety of materials and parts for inspection.

7.1 Disk and Turbine Air Foil Finishing

As the sensor and control technologies advance, those implementations that require tighter tolerances than current robotic technologies can achieve will come within range and become technically feasible.

7.1.3 Laser Drilling of Turbine Blades

Robotic technology is most applicable in processes with large numbers of parts, or a repetitive process performed many times on a small number of parts. Drilling of turbine blades represents a combined opportunity of many holes drilled in each turbine blade and many turbine blades in each engine. While conventional methods of drilling may be used, the full advantage of the robotic system would be realized with a laser drilling technique. It should be noted that there currently are several laser drilling implementations using dedicated machinery rather than robotics, and in fact the dedicated laser drilling stations may be more cost effective than robotic laser drilling stations.

10.0 Various Material Handling Tasks

Potential uses for material handling robots in propulsion are based on the many processing steps that individual parts (such as turbine blades) undergo. Automated handling from the raw investment casting stage to final assembly/welding has the advantage of maintaining parts orientation throughout the manufacturing cycle, and reducing incidental damage caused by inconsistent handling.

4.6 SPACE SECTOR

As with the Ballistic Missile sector, the space sector relies heavily on electronics product, such as guidance and control systems. The robotic implementation opportunities for those products are presented in the description of the opportunities in the Electronics sector.

A. Current Implementations:

4.2.7 Spray Coating of Shuttle Tile Ablator Material

B. Current Opportunities:

4.2.7 Spray Coating

Robotic spray coating can achieve the same improvements for space products as it has in automotive use, but the cost benefits can be greater due to the higher unit cost of coating material, and the benefit to human safety can be greater because of the higher health hazard level of many of the exotic coatings used for space products.

C. Future Opportunities:

2.0 Inspection/Test

Inspection and test functions in the space sector range from incoming test of electronic components for guidance systems to large scale surface and internal inspection of airframe components. Many of these functions are suitable for future robotization and need only a technology transfer from other sectors: for example, wing structure inspection from the aircraft sector and component test from the electronic sector.

7.1 Machining

The implementation opportunities for machining are similar to those described in the aircraft sector. A detailed application example is presented at the end of this section.

8.2 Plastic Molding

The implementation opportunities for plastic molding are similar to those described in detail in the aircraft sector.

Representative Application Example:

Advanced Machining

Advanced machining and metal removal applications are found

within the aerospace community. The majority of these applications will involve the integration of some subset of the following types of equipment and devices:

1. Computer numeric controlled (CNC) machine equipment with a minimum of five axis capability.
2. Freestanding or shuttle mounted articulated arm robotic equipment
3. Overhead gantry style robotic equipment
4. Automatic guided vehicles
5. Full pallet and part shuttle systems
6. Automatic in-process gaging
7. Advanced tool monitoring and sensing features applied with CNC machines
8. Fully integrated supervisory computer control systems with local control for specific manufacturing process monitoring
9. Automatic tool change capability for robots and CNC machines
10. Automatic tool compensation, tool calibration and tool quality detection
11. Adaptive vision control systems designed for in-process alteration of the machining based on part-to-part variation.

Advanced machining systems that combine the aforementioned capital equipment devices, when supplied with appropriate software, can produce a staggering array of different types of aluminum, titanium, inconel and other high strength alloy steel components for airframe use. It is conceivable with present technology that a complete flexible manufacturing system (FMS) can render conventional machine shop practices obsolete. By linking the FMS system to an overall supervisory CAD/CAM system, part and tooling data can be directly downloaded to shop floor level for complete, automatic part fabrication capabilities.

Many similar (although smaller in overall scope) opportunities of this type of FMS concept are presently deployed in the private sector. The same techniques that have been developed and refined in the private sector can be applied on a larger scale to potential aerospace applications.

5.0 Findings/Conclusions

During the course of this study several issues surfaced which warrant attention at an industry-wide level. These are presented and discussed here.

1. Guided Vehicles and Automated Storage/Retrieval Systems. These technologies are outside of the scope of this study, and thus were not specifically identified in the implementation opportunities. However, a large number of respondents mentioned the benefit to be gained from implementing these technologies, and in fact several are actively developing and implementing such systems.

2. Electronics Applications. Electronics manufacturing processes and applications are common to all sectors of aerospace industry, and advances in these areas of manufacturing would be felt across industry. In spite of this level of importance, a relatively small number of manufacturers are implementing robotics for these types of applications, and an even smaller number of companies are attempting the more difficult types of implementations, such as assembly of hybrid circuits and surface mount devices. In view of the potential benefit to be gained from these advances, efforts in the area of robotic assembly of electronics should be a high priority.

3. Analysis of Potential Applications. While most of the respondents expressed the necessity for adequately assessing the cost and return on investment impact of implementing robotics prior to initiating a project, in many instances the greatest payoff to a production line from robotic implementation has come from robotizing the simplest task in the process. Traditional cost/benefit models and return on investment calculations generally have to be modified to adequately account for robotic technology, but there are several cost/benefit analysis models designed specifically for robotics, such as the robot amortization scheme developed by the Air Force Business Management Research Center, and several proprietary schemes.

4. Flexible Manufacturing Systems. Robots as stand-alone systems are gradually giving way to more complex flexible workstations, i.e., groups of automated machinery capable of being controlled to function in unison. In the small batch environment of the aerospace industry, the flexibility gained from an automated workstation is much more beneficial than that from a single dedicated robot. While stand-alone robots will still have their place in many processes, more attention should be paid to incorporating robots into flexible workstations.

5. Technology Transfer. While it is in the interest of the DoD for there to be a high degree of technology transfer from one company to another, in general this contradicts the competition between the individual companies and does not happen often on its own. Specifically, the Air Force has funded the development of many robotic implementations through the Industrial Modernization Incentives Program (IMIP), the Manufacturing Technology (MANTECH) program, and others. While the success of these implementations has benefitted the Air Force, the benefit would be even greater if these successes could be more effectively transferred to other companies. This is nowhere more pronounced than in the case of subcontractors and vendors.

In general, Air Force funding for technology development and implementation projects rarely penetrates past the prime contractor level to the subcontractors and vendors. While there are several IMIP and related programs directed at the subcontractor base, these programs are administered through the prime contractors. A concentrated effort to provide incentives for the implementation of robotics and flexible manufacturing systems directly into the subcontractor and vendor levels of industry should provide great benefit to the Air Force.

6. Inappropriate Applications. Throughout the study, one of the survey questions asked of the industry participants was to identify any robotic implementations that were particularly inappropriate for their situation. The goal of this question was to develop a profile of inappropriate robotic applications, so that Product Division personnel would be able to avoid implementation pitfalls. The responses to this question, however, tended not to be generic but rather very specific to the individual application. For example, an airframe manufacturer reported that a particular airframe painting application was inappropriate for his plant functions. Reporting that aircraft painting with robotics is inappropriate would be misleading, however, as there are currently successful robotic aircraft painting implementations. For this reason, no general conclusions could be drawn from the information collected.

6.0 Summary

Air Force efforts in sponsoring robotics implementation in the aerospace industrial base are constrained by the limited resources available. To maximize the benefits from these resources the Air Force must balance funding for robotics R&D against funding for implementation assistance. This study has identified a broad but uneven range of utilization of robotic technology by the DoD aerospace industry. This uneven utilization can foster inefficiencies in program funding through misapplication of resources. Specifically, implementation assistance may be provided prematurely, where additional R&D may be more effective. Conversely, R&D funds may be expended in areas more suitable for implementation assistance.

The comparison of current applications with current opportunities performed in this study highlights those applications where information transfer is the primary need for immediately increasing robotic utilization. By differentiating those areas primarily requiring information from those requiring developmental efforts, the developmental needs are clearly delineated, forming the basis for a long-term investment strategy.

DETAILED APPLICATION AXIS

1. WELDING

1.1 Arc

1.1.1 MIG Process

- 1.1.1.1 Conventional Fixturing
- 1.1.1.2 Vision Guided
- 1.1.1.3 Through-the-arc Sensing
- 1.1.1.4 Tactile
- 1.1.1.5 Programmable Oscillation
- 1.1.1.6 Thermal Feedback

1.1.2 TIG Process

- 1.1.2.1 Conventional Fixturing
- 1.1.2.2 Vision Guided
- 1.1.2.3 Thermal Feedback

1.2 SPOT WELDING

1.2.1 Aluminum

- 1.2.1.1 Conventional Fixturing
- 1.2.1.2 Vision Guided

1.2.2 Ferrous, Non-ferrous

- 1.2.2.1 Conventional Fixturing
- 1.2.2.2 Vision Guided

1.3 LASER

- 1.3.1 Non Filler-Parent Bonded
- 1.3.2 Filler Material Application
- 1.3.3 Non-ferrous Bonding

1.4 ELECTRON BEAM

1.4.1 Aluminum Process

- 1.4.1.1 Conventional Fixtures
- 1.4.1.2 Vision Guided

1.4.2 Ferrous/Non-ferrous

- 1.4.2.1 Conventional Fixturing
- 1.4.2.2 Vision Guided

1.5 FUSION WELDING

- 1.5.1 Ferrous Welding
- 1.5.2 Non-Ferrous Welding

2.0 INSPECTION

2.1 SURFACE/DIMENSIONAL

- 2.1.1 Eddy Current
- 2.1.2 Photometric
- 2.1.3 Optical (Vision)
- 2.1.4 Laser Scanning
- 2.1.5 Profilometry
- 2.1.6 Tactile Probe
- 2.1.7 Surface Finish
 - 2.1.7.1 RMS
 - 2.1.7.2 Reflectivity
 - 2.1.7.3 Hardness

2.2 INTERNAL

- 2.2.1 Acoustic/Ultrasonic
- 2.2.2 Radiation Testing
- 2.2.3 Mass Moment Measuring
- 2.2.4 Volumetric Gauging
- 2.2.5 Mechanical Parameter
 - 2.2.5.1 Ductility
 - 2.2.5.2 Tensile Strength
 - 2.2.5.3 Material Memory
 - 2.2.5.4 Impact Resistance
 - 2.2.5.5 Temperature Degradation

2.3 FUNCTIONALITY (ASSEMBLY AND SUBASSEMBLY)

- 2.3.1 Circuit Path Verification
- 2.3.2 Electronic Function Test
- 2.3.3 Mechanical Function Test

3.0 ASSEMBLY

3.1 OPEN TOLERANCE ASSEMBLY

- 3.1.1 Mechanical Press/Force
- 3.1.2 Mechanical Compliance
- 3.1.3 Mechanical Compliance/With Digital Control

3.2 CLOSE TOLERANCE ASSEMBLY

- 3.2.1 Vision Assisted
- 3.2.2 Tactile Sensing
- 3.2.3 Linear Parametric Detection

3.3 FASTENER ASSEMBLY

- 3.3.1 Rivets
 - 3.3.1.1 With Sensory Feedback
 - 3.3.1.2 Without Sensory Feedback
- 3.3.2 Press Fit Details
 - 3.3.2.1 With Sensory Feedback
 - 3.3.2.2 Without Sensory Feedback
- 3.3.3 Threaded Fasteners
 - 3.3.3.1 With Sensory Feedback
 - 3.3.3.2 Without Sensory Feedback

4.0 COATING

4.1 PAINT APPLICATION

- 4.1.1 Electrostatic
- 4.1.2 Conventional
- 4.1.3 Secondary Processes
- 4.1.4 Lamp Curing
- 4.1.5 Depainting

4.2 ENGINEERED SURFACE COATING

- 4.2.1 Detonation Gun Deposition
- 4.2.2 Plasma Spray Deposition
- 4.2.3 Gas Spray Deposition
- 4.2.4 Electrolytic Deposition
- 4.2.5 Vacuum Deposition
- 4.2.6 Spray Welding
- 4.2.7 Other Material Coating (Polyurethane, etc.)

4.3 OTHER

- 4.3.1 Gas Vapor
- 4.3.2 Process Immersion

5.0 SEALING/ADHESIVE

5.1 MECHANICAL BONDING

- 5.1.1 Aneorobic
- 5.1.2 Air Cure
- 5.1.3 Epoxy Based
- 5.1.4 Specialty Bonding

5.2 ASSEMBLY BONDING

- 5.2.1 Adhesive Dispensing Monitoring
- 5.2.2 Vision Guided

5.3 SEALING APPLICATION

- 5.3.1 Environmental Application
- 5.3.2 Pressurized Requirements
- 5.3.3 Vibration Damping

6.0 SURFACE PREPARATION

6.1 GRINDING/DEBURR

- 6.1.1 Conventional Fixturing
- 6.1.2 Tactile Sensing
- 6.1.3 Vision Guided

6.2 COATING REMOVAL-MECHANICAL

- 6.2.1 With Adaptive Control
- 6.2.2 Without Adaptive Control

6.3 COATING REMOVAL - CHEMICAL

- 6.3.1 With Adaptive Control
- 6.3.2 Without Adaptive Control

6.4 SURFACE HARDENING - MECHANICAL

- 6.4.1 Hammering
- 6.4.2 Roll Forming
- 6.4.3 Stress Treating
- 6.4.4 Peening

6.5 POLISHING

7.0 MATERIAL REDUCTION

7.1 MACHINING

- 7.1.1 Milling

- 7.1.1.1 With Sensory Feedback
- 7.1.1.2 Without Sensory Feedback

7.1.2 Routing

- 7.1.2.1 With Sensory Feedback
- 7.1.2.2 Without Sensory Feedback

7.1.3 Drilling

- 7.1.3.1 With Sensory Feedback
- 7.1.3.2 Without Sensory Feedback

7.1.4 Grinding

- 7.1.4.1 With Sensory Feedback
- 7.1.4.2 Without Sensory Feedback

7.1.5 Stamping

- 7.1.5.1 With Sensory Feedback
- 7.1.5.2 Without Sensory Feedback

7.1.6 Cutting

7.1.6.1 Mechanical

- 7.1.6.1.1 With Sensory Feedback
- 7.1.6.1.2 Without Sensory Feedback

7.1.6.2 Laser

- 7.1.6.2.1 With Sensory Feedback
- 7.1.6.2.2 Without Sensory Feedback

7.1.6.3 Water Jet

- 7.1.6.3.1 With Sensory Feedback
- 7.1.6.3.2 Without Sensory Feedback

7.1.6.4 Plasma Cutting

- 7.1.6.4.1 With Sensory Feedback
- 7.1.6.4.2 Without Sensory Feedback

7.2 NON-MACHINING

7.2.1 CHEMICAL MILLING

- 7.2.1.1 With Sensory Feedback
- 7.2.1.2 Without Sensory Feedback

7.2.2 ETCHING

- 7.2.2.1 With Sensory Feedback
- 7.2.2.2 Without Sensory Feedback

7.2.3 ELECTRICAL DISCHARGE

- 7.2.3.1 With Sensory Feedback
- 7.2.3.2 Without Sensory Feedback

8.0 CASTING (All Requiring Process Control)

8.1 METAL

- 8.1.1 Die Cast Extraction
- 8.1.2 Sand Cast Process
- 8.1.3 Investment Casting
- 8.1.4 Permanent Mold

8.2 PLASTIC MOLDING

- 8.2.1 Injection
- 8.2.2 Compression
- 8.2.3 Lay-up
- 8.2.4 Liquid Cast
- 8.2.5 Open Mold

9.0 FORGING (All Requiring Process Control)

9.1 ALUMINUM

- 9.1.1 High Strength
- 9.1.2 General

9.2 FERROUS, NON-FERROUS

- 9.2.1 Upsetting
- 9.2.2 Swaging
- 9.2.3 Cold Heading
- 9.2.4 Warm Form
- 9.2.5 Open Die
- 9.2.6 Closed Die
- 9.2.7 Hammer Operation
- 9.2.8 Extrusion
- 9.2.9 Super Plastic Forming
- 9.2.10 Other Metal Forming

10.0 MATERIAL HANDLING

10.1 CONVENTIONAL

- 10.1.1 Automatic Storage/Retrieval
- 10.1.2 Automatic Guided Vehicles
- 10.1.3 Preformed Plastic Dunnage and Pallets
- 10.1.4 Power and Free Conveyor
- 10.1.5 Indexable Conveyor
- 10.1.6 Pallet Distribution System
- 10.1.7 Machine Load/Unload

10.2 SPECIAL CONSIDERATIONS/ENVIRONMENTS

- 10.2.1 Clean Room
- 10.2.2 Elevated Temperature
- 10.2.3 Lowered Temperature
- 10.2.4 Explosion Proofing
- 10.2.5 Radioactive
- 10.2.6 Fabric/Composite
- 10.2.7 Delicate

1. COMPANY NAME:
2. PLANT ADDRESS:

3. CONTACT NAME:
4. CONTACT TITLE:
5. PHONE NUMBER:

6. Please give a brief description of any robotic implementations currently on your plant floor (e.g., assembling small electronic subassemblies, TIG welding of structural components, etc.)
7. Are these implementations using any specialty technology (e.g., vision sensing, etc.)?
8. Were these implementations funded in whole or part through any DoD incentive programs (e.g., Navy MANTECH, Air Force IMIP, etc.)?
 - 8a. If so, what were the approximate funding levels?
9. Briefly describe (quantitatively, if possible) the effect of these robot implementations on product
 - Cost?
 - Throughput?
 - Quality?

(For each answer to 10 and 11, please include whether the motivating factor would more likely be reduced cost, increased throughput, increased quality, or a combination?)
10. Please describe any other plant floor processes that you have considered or might consider for near term (1-3 years) robotization.
11. Please describe any other plant floor processes that you have considered or might consider for far term (> 3 years) robotization.
12. Are there any plant floor processes that would be particularly inappropriate for robotization?
13. Do you have any other comments?

LIST OF COMPANIES SUPPLYING INPUT TO STUDY

<u>Company</u>	<u>Division</u>	<u>Location</u>
AAI		Baltimore, MD
Aerojet	Ordnance	Downey, CA
Aerojet	Strategic Propulsion	Sacramento, CA
AF Plant 44 (Hughes Aircraft)	Missile Systems Group	Tucson, AZ
AVCO	Aerostructures	Nashville, TN
AVCO	Plant 47	Wilmington, MA
Boeing Military Airplane Co.		Wichita, KS
Brunswick Corporation		Marion, VA
Cincinnati Electronics		Cincinnati, OH
Cleveland Pneumatic		Cleveland, OH
Day and Zimmerman		Parson, KS
Eaton	AIL	Long Island, NY
Fairchild Republic		Long Island, NY
Garrett	Pneumatic Systems Div.	Tempe, AZ
Garrett	Turbine Engine Company	Phoenix, AZ
General Dynamics		Fort Worth, Texas
General Electric	Space Systems Division	Philadelphia, PA
General Motors	Delco Electronics Div.	Goleta, CA
Hercules		McGregor, Texas
Honeywell		St. Louis Park, MN
Honeywell	Twin City Army Amm.	New Brighton, Mi
Hughes Aircraft Company		Newport, CA
Hughes Aircraft Company	Radar Systems Division	Los Angeles, CA
IBM	Owega	Owega, NY
Lear Siegler		Maple Heights, OH
Lockheed	Georgia	Marietta, GA
Martin Marietta	Orlando Aerospace	Orlando, FL
McDonnell Douglas	Long Beach North	Long Beach, CA
McDonnell Douglas	Long Beach South	Long Beach, CA
McDonnell Douglas,	Long Beach Torrance	Torrance, CA
Morton Thiokol		Brigham City, UT
Northrop Corp.		Hawthorn, CA
Northrop Corp.	Precision Products Div.	Norwood, MA
Pratt & Whitney		East Hartford, CT
Questron Corporation		San Diego, CA
Raytheon	Missile Systems Division	Lowell, MA
Reflectone		Tampa, FL
Rockwell International	Autonetics Strategic Sys	Anaheim, CA
Rosemont		Minneapolis, MN
Sierracin/Sylmar		Sylmar, CA
Simmonds Precision		Norwich, NY
Singer	Link Flight Systems Div.	Binghamton, NY
Sundstrand		Rockford, IL.
Teledyne	CAE	Toledo, OH
Teledyne	MEC	Palo Alto, CA

Telephonics
Texas Instruments
Vernitron
Vought Corporation
Watkins Johnson
Westinghouse
Whittaker Controls
Williams International

LTV Aerospace & Defense
Defense Electronics Ctr

Long Island, NY
Midland, Texas
Bedford, Ohio
Dallas, TX
Palo Alto, CA
Baltimore, MD
N. Hollywood, CA
Walled Lake, MI

APPENDIX D

Current Applications Matrix

Current Applications Matrix

KEY

1.0 Welding	2.0 Inspection	3.0 Assembly	4.0 Painting/Coating	5.0 Sealing/Adhesive	6.0 Surface Preparation	7.0 Material Reduction	8.0 Casting	9.0 Forging	10.0 Material Handling
D-3	D-6			D-12			D-13		D-17
D-4	D-7						D-14		D-18
D-5	D-8						D-15		D-19
	D-9						D-16		D-20
	D-10								D-21
	D-11								

NOTE: The following pages may be arranged in the order shown to display the entire matrix.

1.0 WELDING

2.0 INSPECTION

Company ID No. : 1
 Non-aerospace Application
 Appl. Axis Code : 1.1
 Task Performed : ARC WELDING
 Other Comments :
 Source : ROB TODAY 10/85 P.16

Company ID No. : 2
 Aerospace Application
 Appl. Axis Code : 1.1
 Task Performed : WELDING
 Other Comments :
 Source : MATRIX 2

Company ID No. : 3
 Aerospace Application
 Appl. Axis Code : 1.1
 Task Performed : WELDING
 Other Comments :
 Source : MATRIX 2

Company ID No. : 4
 Non-Aerospace Application
 Appl. Axis Code : 1.1.1.1
 Task Performed : ARC WELDING
 Other Comments : SIMPLE ARC WELDING TASKS
 Source : ROB TODAY 12/84 P.29

Company ID No. : 5
 Non-aerospace Application
 Appl. Axis Code : 1.1.1.1
 Task Performed : ARC WELDING
 Other Comments : STRAIGHTFORWARD
 Source : ROBOTIQUE, IV, 1985

Company ID No. : 6
 Non-aerospace Application
 Appl. Axis Code : 1.1.1.2
 Task Performed : ROBOTIC WELDING WITH VISION
 Other Comments : BETA TEST OF ADV ROB INC. DEV.
 Source : ROB TODAY 12/84 P.24

Company ID No. : 7
 Non-aerospace Application
 Appl. Axis Code : 1.1.1.2
 Task Performed : LIGHT-STRIP ASSISTED ARC WELD
 Other Comments : AUTOMOBILE TRAILING AXLE APPL.
 Source : ROBOTIQUE, IV, 1985

15
 Aerospace Application
 2.0
 INSPECTION
 IMIP FUNDING
 MATRIX 2

16
 Aerospace Application
 2.1
 TESTING OF B-1 ARCRFT PANELS
 PURCHASED WITH 100K IMIP
 MATRIX 2

17
 Aerospace Application
 2.1.1
 EDDY CURRENT INSP OF T. DISKS
 MANTECH
 REPTTECH 84 P.32

18
 Aerospace Application
 2.1.1
 INSP AND DERIVETING PLANE
 INTEGRATED SYSTEM
 REPTTECH 84 P.32

1
 Non-aerospace Application
 2.1.3
 DIMENSIONAL VISION INSP
 WORKS WITH WELDING STATION
 ROB TODAY 12/85 P.26

19
 Non-aerospace Application
 2.1.3
 INSP OF SMD PLACEMENT
 "MOST" ACCURATE TO DATE
 MAN ENG 12/85 P.45

20
 Aerospace Application
 2.1.4
 DRILL, GRIND, INSP COMPOSITES
 CASPIN MANTECH PROJECT
 AEROSPACE 8.85 P.4

1.0 WELDING

2.0 INSPECTION

Company ID No. : 8
 Non-aerospace Application
 Appl. Axis Code : 1.1.1.3
 Task Performed : ROBOTIC WELDING WITH SENSORS
 Other Comments : HUMAN ASSISTED
 Source : MAN ENG 10/85 P.25

Company ID No. : 9
 Aerospace Application
 Appl. Axis Code : 1.1.1.3
 Task Performed : ROBOTIC WELDING OF END-MILLS
 Other Comments : USES PROCESS MONITORING
 Source : ROB TODAY 2/85 P.26

Company ID No. : 10
 Non-aerospace Application
 Appl. Axis Code : 1.1.1.3
 Task Performed : PLASMA-TRANSFERRED ARC WELD
 Other Comments :
 Source : MAN ENG 2/85 P.26

Company ID No. : 11
 Aerospace Application
 Appl. Axis Code : 1.1.2.3
 Task Performed : PULSED GTA WELD
 Other Comments : FAB. AND REWELD - ENG. PARTS
 Source : SME MS85-185

Company ID No. : 12
 Non-aerospace Application
 Appl. Axis Code : 1.1.5
 Task Performed : ARC WELDING
 Other Comments : WELD WORKCELL FOR MLRS
 Source : ROB TODAY 8/85 P.12

Company ID No. : 13
 Non-aerospace Application
 Appl. Axis Code : 1.2
 Task Performed : SPOT WELDING, DELICATE ASMBLY
 Other Comments : VISION ASSIJDTED
 Source : ROB TODAY 2/85 P.35

Company ID No. : 1
 Non-aerospace Application
 Appl. Axis Code : 1.2
 Task Performed : SPOT WELDING
 Other Comments :
 Source : ROB TODAY 10/85 P.16

21
 Non-aerospace Application
 2.1.7
 ELECTRO-OPTIC INSP OF DEFECTS
 LARGE SENSOR FOR CAR FINISHES
 ROB TODAY 2/85 P.14

22
 Non-aerospace Application
 2.1.7
 SURFACE INSPECTION/GAGING
 ROB TODAY 2.85 P.31

23
 Aerospace Application
 2.2.1
 ULTRASONIC INSPECTION
 WATER JET INSP OF PANELS
 MAN ENG 2/85 P.53

24
 Aerospace Application
 2.2.1
 ULTRASONIC INSP OF COMPOSITES
 WATER JETS
 MAN ENG 9/84 P.49

25
 Aerospace Application
 2.2.1
 ULTRASONIC INSP OF COMPOSITES
 WATER JETS
 MAN ENG 9/85 P.97

26
 Aerospace Application
 2.2.2
 LARGE SCALE NDI INSP GANTRY
 SEE ROBOTS IS AERO. CONF.
 REPTTECH 84 P. 105

17
 Aerospace Application
 2.2.2
 X-RAY INSP OF TURBINE BLADES
 ROBOT HOLDS WORKPEICE
 MAN ENG 2/86 P.23

1.0 WELDING

2.0 INSPECTION

Company ID No. : 14
Aerospace Application
Appl. Axis Code : 1.2
Task Performed : SPOT WELDING
Other Comments :
Source : MATRIX 2

17
Aerospace Application
2.2.2
X-RAY INSP OF TURBINE BLADES

ROB TODAY 4/86 P.12

Company ID No. :
Appl. Axis Code :
Task Performed :
Other Comments :
Source :

27
Non-aerospace Application
2.2.4
VOLUMETRIC INSP OF CARS
TACTILE SENSING ALSO
ROB TODAY 4/85 P.26

Company ID No. :
Appl. Axis Code :
Task Performed :
Other Comments :
Source :

28
Non-aerospace Application
2.3.2
INSPECTION OF PC BOARDS
18 ROBOT FLEXIBLE STATION
ROB TODAY 10/84 P.18

Company ID No. :
Appl. Axis Code :
Task Performed :
Other Comments :
Source :

1
Non-aerospace Application
2.3.2
MATL HANDLING FOR CALIBRATION
VOLTAGE + DIMENSIONAL CAL.
ROBOTIQUE, IV, 1985

Company ID No. :
Appl. Axis Code :
Task Performed :
Other Comments :
Source :

Company ID No. :
Appl. Axis Code :
Task Performed :
Other Comments :
Source :

Company ID No. :
Appl. Axis Code :
Task Performed :
Other Comments :
Source :

3.0 ASSEMBLY

4.0 PAINTING/COATING

Company ID No. : 3
 Aerospace Application
 Appl. Axis Code : 3.0
 Task Performed : ASSEMBLY
 Other Comments :
 Source : MATRIX 2

Company ID No. : 29
 Aerospace Application
 Appl. Axis Code : 3.1
 Task Performed : CABLE HARNESS ASS'Y
 Other Comments : PILOT GET PRICE, REACH PROG.
 Source : AEROSPACE 8/85 P.6

Company ID No. : 30
 Non-aerospace Application
 Appl. Axis Code : 3.1
 Task Performed : COMPOSITE WINDING
 Other Comments : FOR CYLINDRICAL PARTS
 Source : ROB TODAY 8/84 P.10

Company ID No. : 31
 Aerospace Application
 Appl. Axis Code : 3.1
 Task Performed : INDUSTRIAL SOLVENT ASSEMBLY
 Other Comments :
 Source : MATRIX 2

Company ID No. : 1
 Non-aerospace Application
 Appl. Axis Code : 3.1.1
 Task Performed : ASS'Y OF MASTER CYL. SPRINGS
 Other Comments :
 Source : ROBOTIQUE, IV, 1985

Company ID No. : 32
 Aerospace Application
 Appl. Axis Code : 3.1.1
 Task Performed : ASSEMBLE BRACKETS
 Other Comments :
 Source : MATRIX 2

Company ID No. : 33
 Non-aerospace Application
 Appl. Axis Code : 3.1.1
 Task Performed : ASS'Y OF CIRCUIT BREAKERS
 Other Comments : IBM 7535 SCARA ROBOT
 Source : ROB TODAY 4/86 P.12

15
 Aerospace Application
 4.1
 SPRAY COATING
 TECHMOD
 MATRIX 2

1
 Non-aerospace Application
 4.1.2
 SPRAY PAINTING SYSTEM
 FLEXIBLE BACKUP, PROC. MON
 ROB TODAY 4/85 P.52

4
 Non-aerospace Application
 4.1.2
 SPRAY PAINTING WITH VISION
 DETERMINES PART SILHOUETTE
 ROB TODAY 12/84 P.30

52
 Non-aerospace Application
 4.1.2
 ADVANCED ROBOTIC PAINT LINE
 SEE RECORD 77, 79
 MAN ENG 9/84 P.62

53
 Non-aerospace Application
 4.1.2
 SPRAY PAINT - PEICE MARKING
 DOS-SPARY PAINTER 'ISED
 MAN ENG 8/85 P.21

1
 Non-aerospace Application
 4.1.2
 SPRAY PAINTING CAR BODIES
 STRAIGHTFORWARD
 MAN ENG 9/84 P.62

52
 Non-aerospace Application
 4.1.3
 ADVANCED ROBOTIC PAINT LINE
 SEE RECORD 76, 77
 MAN ENG 9.84 P.62

3.0 ASSEMBLY

Company ID No. : 17
 Non-aerospace Application
 Appl. Axis Code : 3.1.2
 Task Performed : COARSE ASS'Y OF FIBRE OPTICS
 Other Comments : POINT-OF-USE CONCEPT
 Source : ROB TODAY 10/84 P.48

Company ID No. : 34
 Non-aerospace Application
 Appl. Axis Code : 3.1.2
 Task Performed : ASS'Y OF CAR WINDSHIELDS
 Other Comments : LIGHT-STRIPE SENSING - ALIGN
 Source : ROB TODAY 8/84 P.18

Company ID No. : 29
 Aerospace Application
 Appl. Axis Code : 3.2
 Task Performed : CIRCUIT BOARD ASS'Y
 Other Comments : PILOT GET PRICE, SEAS PROG.
 Source : AEROSPACE 8/85 P.6

Company ID No. : 29
 Non-aerospace Application
 Appl. Axis Code : 3.2
 Task Performed : PC BOARD COMPONENT INSERTION
 Other Comments : PROCESS MONITORING, PART REJECT
 Source : ROB TODAY 12/84 P.62

Company ID No. : 35
 Non-aerospace Application
 Appl. Axis Code : 3.2
 Task Performed : HIGH SPEED COMPONENT INSERTION
 Other Comments : FIXTURING
 Source : ROB TODAY 2/85 P.30

Company ID No. : 17
 Non-aerospace Applicaton
 Appl. Axis Code : 3.2
 Task Performed : LIGHT ASS'Y, 3 FING. GRIPPER
 Other Comments :
 Source : SME MS840228

Company ID No. : 23
 Aerospace Application
 Appl. Axis Code : 3.2
 Task Performed : PC BOARD STUFFING
 Other Comments :
 Source : MATRIX 2

4.0 PAINTING/COATING

54
 Non-aerospace Application
 4.2.3
 GRIT BLAST AND ARC-SPRAY
 20% MTL, 75% COST SAVINGS
 ROB TODAY 10/84 P.14

55
 Non-aerospace Application
 4.2.7
 SPRAY COAT WITH POLYURETHANE
 MAN ENG 4/85 P.23

56
 Aerospace Application
 4.2.7
 SPARY COATING OF PC BOARDS
 MATRIX 2

32
 Aerospace Application
 4.2.7
 SPRAY ADHESIVES
 MATRIX 2

52
 Non-aerospace Application
 4.3.2
 ADVANCED ROBOTIC PAINT LINE
 SEE RECORD 76, 77
 MAN ENG 9/84 P.62

3.0 ASSEMBLY

Company ID No. : 36
Aerospace Application
Appl. Axis Code : 3.2
Task Performed : WIRE BONDING, IC'S
Other Comments :
Source : MATRIX 2

Company ID No. : 37
Aerospace Application
Appl. Axis Code : 3.2
Task Performed : ASS'Y OF PC BOARDS - SMD'S
Other Comments :
Source : MATRIX 2

Company ID No. : 38
Aerospace Application
Appl. Axis Code : 3.2
Task Performed : WELDING APPLICATIONS - PC BOARDS
Other Comments :
Source : MATRIX 2

Company ID No. : 39
Aerospace Application
Appl. Axis Code : 3.2
Task Performed : COMPONENT INSERTION
Other Comments : ADAPTIVE CONTROL
Source : MATRIX 2

Company ID No. : 40
Aerospace Application
Appl. Axis Code : 3.2
Task Performed : PC BOARD INSERTION
Other Comments : 5 ROBOT STATION
Source : MATRIX 2

Company ID No. : 41
Non-aerospace Application
Appl. Axis Code : 3.2.1
Task Performed : DELICATE ASS'Y, FABRICATION
Other Comments : ASS'Y AND INSP OF KEYPADS
Source : MAN ENG 10/85 P.29

Company ID No. : 42
Non-aerospace Application
Appl. Axis Code : 3.2.1
Task Performed : SPOT WELDING, DELICATE ASS'Y
Other Comments : VISION ASSISTED
Source : ROB TODAY 2/85 P.35

4.0 PAINTING/COATING

3.0 ASSEMBLY

Company ID No. : 24
Aerospace Application
Appl. Axis Code : 3.2.1
Task Performed : VISION ASSISTED ASS'Y
Other Comments : WORKING MODEL READY FOR USE
Source : SME MS85-186

Company ID No. : 24
Aerospace Application
Appl. Axis Code : 3.2.1
Task Performed : ASSEMBLE SMD'S ONTO PC BOARDS
Other Comments : VISION ASSISTED
Source : MAN ENG 12/85 P.44

Company ID No. : 43
Non-aerospace Application
Appl. Axis Code : 3.2.1
Task Performed : ASSEMBLY OF PC BOARDS
Other Comments : VISION ASSISTED PART ACQUIS.
Source : ROB TODAY 6/85 P.53

Company ID No. : 1
Aerospace Application
Appl. Axis Code : 3.2.1
Task Performed : ASS'Y OF SMD'S
Other Comments : DEVELOPED UNDER AIR FORCE ITM
Source : MATRIX 2

Company ID No. : 44
Non-aerospace Application
Appl. Axis Code : 3.2.2
Task Performed : DEL ASS'Y OF HEATER CONTROLS
Other Comments : PROGRAMMABLE PARTS FEEDING
Source : ROB TODAY 10/84 P.50

Company ID No. : 45
Non-aerospace Application
Appl. Axis Code : 3.2.2
Task Performed : ASS'Y OF HARD DISK SYSTEMS
Other Comments : FORCE SENSOR ASSISTED
Source : ROB TODAY 4/85 P.35

Company ID No. : 39
Non-aerospace Application
Appl. Axis Code : 3.2.2
Task Performed : DELICATE ASS'Y OF PRINTER PANELS
Other Comments : IR ASSISTED ALSO
Source : ROB TODAY 2/85 P.26

4.0 PAINTING/COATING

3.0 ASSEMBLY

Company ID No. : 39
Non-aerospace Application
Appl. Axis Code : 3.2.3
Task Performed : DELICATE ASS'Y OF PC BOARDS
Other Comments :
Source : ROB TODAY 10/84 P.49

Company ID No. : 46
Non-aerospace Application
Appl. Axis Code : 3.2.3
Task Performed : ASS'Y OF DISK DRIVES
Other Comments : CLEAN ROOM, MINIMAL SENSING
Source : ROB TODAY 2/85 P.29

Company ID No. : 47
Non-aerospace Application
Appl. Axis Code : 3.2.3
Task Performed : DELICATE ASS'Y AND SPRAY COAT
Other Comments : ELIMINATE INTERMEDIATE INVENTORY
Source : ROB TODAY 2/85 P.30

Company ID No. : 48
Non-aerospace Application
Appl. Axis Code : 3.2.3
Task Performed : ASS'Y BY ULTRASONIC WELD
Other Comments :
Source : ROB TODAY 4/84 P.94

Company ID No. : 49
Aerospace Application
Appl. Axis Code : 3.2.3
Task Performed : AT'CH CERAMIC SUBSTRATES
Other Comments : NAVY/AF MANTECH - MICROWAVE
Source : ROB TODAY 6/85 P.16

Company ID No. : 50
Aerospace Application
Appl. Axis Code : 3.3.1
Task Performed : DRILL AND RIVET OF SMALL SUBS
Other Comments :
Source : MATRIX 2

Company ID No. : 32
Aerospace Application
Appl. Axis Code : 3.3.1
Task Performed : INSERT AND PULL RIVETS
Other Comments :
Source : MATRIX 2

4.0 PAINTING/COATING

3.0 ASSEMBLY

4.0 PAINTING/COATING

Company ID No. : 9
Aerospace Application
Appl. Axis Code : 3.3.1.1
Task Performed : RIVET A'CRFT STRUCTURAL COMPNTS.
Other Comments : STORAGE + RETRIEVAL, VISION
Source : SME MS840226

Company ID No. : 24
Aerospace Application
Appl. Axis Code : 3.3.1.1
Task Performed : VISION ASSISTED ASSEMBLY
Other Comments : WORKING MODEL READY FOR USE
Source : SME MS85-186

Company ID No. : 33
Non-aerospace Application
Appl. Axis Code : 3.3.3.1
Task Performed : ASS'Y OF CIRCUIT BREAKERS
Other Comments : IBM SCARA 7535 SCARA ROBOT
Source : ROB TODAY 4/86 p.12

Company ID No. : 51
Non-aerospace Application
Appl. Axis Code : 3.3.3.2
Task Performed : ASSEMBLING PROCESSES FOR ENGINES
Other Comments : BOLT INSERTION AND TORQUING.
Source : ROB TODAY 12/84 P.49

Company ID No. :
Appl. Axis Code :
Task Performed :
Other Comments :
Source :

Company ID No. :
Appl. Axis Code :
Task Performed :
Other Comments :
Source :

Company ID No. :
Appl. Axis Code :
Task Performed :
Other Comments :
Source :

5.0 SEALING/ADHESIVE

6.0 SURFACE PREPARATION

Company ID No.	: 57	3
Appl. Axis Code	: Non-aerospace Application	Aerospace Application
Task Performed	: 5.1	6.1
Other Comments	: MULTIPLE ROBOT SEALANT APP.	DEBURRING
Source	: CAR DOORS	MATRIX 2
	: MAN ENG 7/85 P.35	
Company ID No.	: 58	2
Appl. Axis Code	: Non-aerospace Application	Aerospace Application
Task Performed	: 5.1.4	6.1.1
Other Comments	: ADHESIVE/SEALANT FOR CAR	DEBURRING TUBE ENDS PRIOR
Source	: WINDSHIELDS	TO BENDING
	: ROB TODAY 12/85 P.44	SME MF840132
Company ID No.	: 59	61
Appl. Axis Code	: Non-aerospace Application	Aerospace Application
Task Performed	: 5.1.4	6.1.1
Other Comments	: APPLICATION OF LUBRICANT	BRUSH DEBURRING
Source	: MAN ENG 12/85 P.44	MATRIX 2
Company ID No.	: 44	61
Appl. Axis Code	: Non-aerospace Application	Non-aerospace Application
Task Performed	: 5.2.1	6.1.2
Other Comments	: SEALANT APP - CAR PANELS	DEBURRING STATION
Source	: GROWING IN POPULARITY	BUILT BY E. S-I INC OF ALBANY
	: ROB TODAY 10/84 P.35	MAN ENG 9/84 P.28
Company ID No.	: 60	54
Appl. Axis Code	: Non-aerospace Application	Non-aerospace Application
Task Performed	: 5.2.2	6.2.2
Other Comments	: VISION ASSISTED SEALANT APP	GRIT BLASTING + ARC SPRAYING
Source	: VOID-IN-BEAD DETECTION	ROB TODAY 10/84 P.14
	: SME MS85-192	
Company ID No.	: 28	
Appl. Axis Code	: Non-aerospace Application	
Task Performed	: 5.3	
Other Comments	: SEALANT DISPENSING	
Source	: MULTI ROBOT INSTALLATION	
	: ROB TODAY 4/86 P.12	
Company ID No.	: 1	
Appl. Axis Code	: Non-aerospace Application	
Task Performed	: 5.3.3	
Other Comments	: LIQUID SEALANT APPLICATION	
Source	: LOCKTITE CORP, GMF ROBOT	
	: ROB TODAY 10/84 P.42	

7.0 MATERIAL REDUCTION

8.0 CASTING

Company ID No. : 17
 Aerospace Application
 Appl. Axis Code : 7.1
 Task Performed : AUTOMATED MACHINING CENTER
 Other Comments : GET PRICE PROGRAM
 Source : AEROSPACE 8/85 P.7

Company ID No. : 62
 Aerospace Application
 Appl. Axis Code : 7.1
 Task Performed : BROACHING COMPRESSOR BLADES
 Other Comments : PART OF A LARGE AUTOMATED SYS.
 Source : ROB TODAY 8/84 P.27

Company ID No. : 62
 Aerospace Application
 Appl. Axis Code : 7.1
 Task Performed : MACHINING
 Other Comments : HEAVY MANTECH/IMIP FUNDING
 Source : MATRIX 2

Company ID No. : 62
 Aerospace Application
 Appl. Axis Code : 7.1.1
 Task Performed : SONIC MACHINING CELL
 Other Comments : HEAVY MANTECH/IMIP FUNDING
 Source : MATRIX 2

Company ID No. : 9
 Aerospace Application
 Appl. Axis Code : 7.1.1.1
 Task Performed : ROUTING C-130 RIB CAPS
 Other Comments : TACTILE SENSING, CMT3
 Source : ROB TODAY 8/85 P.12

Company ID No. : 2
 Aerospace Application
 Appl. Axis Code : 7.1.1.1
 Task Performed : DRILLING, ROUTING
 Other Comments : PILOT MANTECH PROGRAM, F-16
 Source : AEROSPACE 8/85 P.3

Company ID No. : 17
 Aerospace Application
 Appl. Axis Code : 7.1.1.1
 Task Performed : DEBURRING
 Other Comments : VISCOUS FLUID MOUNT
 Source : MAN ENG 1/86 P.27

68
 Non-aerospace Application
 8.1.1
 LOAD/UNLOAD DIE CAST MACH.
 OLDER APPLICATION
 INDUS ROBOT (TANNER)

1
 Non-aerospace Application
 8.1.2
 CORE TRANSFER FOR CASTINGS
 STRAIGHTFORWARD
 MAN ENG 6/85 P.18

69
 Non-aerospace Application
 8.1.3
 INVESTMENT CASTING
 OLDER APPLICATION
 INDUS ROBOT (ROBOT)

70
 Non-aerospace Application
 8.1.3
 INVESTMENT CASTING
 OLDER APPLICATION
 INDUS ROBOT (TANNER)

71
 Non-aerospace Application
 8.1.3
 INVEST. CAST, RINSE, DIP, SEAL
 STRAIGHTFORWARD
 ROB TODAY 4/84 P.42

72
 Non-aerospace Application
 8.2.1
 LOAD/UNLOAD PLASTIC MOLD
 OLDER APPLICATION
 INDUS ROBOT (TANNER)

7.0 MATERIAL REDUCTION

Company ID No. : 25
Aerospace Application
Appl. Axis Code : 7.1.1.2
Task Performed : HONEYCOMB CORE DETAIL MANUF.
Other Comments :
Source : SME MS85-196

Company ID No. : 9
Aerospace Application
Appl. Axis Code : 7.1.1.2
Task Performed : DRILL, ROUT, DEBURR C-5B FUSELAGE
Other Comments : COMB. INCREASES EFFECTIVENESS
Source : SME MS85-202

Company ID No. : 20
Aerospace Application
Appl. Axis Code : 7.1.3
Task Performed : DRILL, ROUT F-111 SHEET METAL
Other Comments : MACHINE CONTROL LANG. OFF-LINE
Source : ROB TODAY 10/84 P.14

Company ID No. : 63
Aerospace Application
Appl. Axis Code : 7.1.3
Task Performed : DRILLING OF CANAPIES
Other Comments : MANTECH, F-16, F-18, AV-8B
Source : AEROSPACE 8/85 P.4

Company ID No. : 9
Aerospace Application
Appl. Axis Code : 7.1.3
Task Performed : DRILL, ROUT, DEBURR C-5B FUSELAGE
Other Comments : COMB. INCREASES EFFECTIVENESS
Source : SME MS85-202

Company ID No. : 2
Aerospace Application
Appl. Axis Code : 7.1.3.1
Task Performed : DRILLING, ROUTING
Other Comments : PILOT MANTECH PROGRAM, F-16
Source : AEROSPACE 8/85 P.3

Company ID No. : 20
Aerospace Application
Appl. Axis Code : 7.1.3.1
Task Performed : DRILL, GRIND, INSP. COMPOSITES
Other Comments : CASPIN MANTECH PROJECT
Source : AEROSPACE 8/85 P.4

8.0 CASTING

7.0 MATERIAL REDUCTION

8.0 CASTING

Company ID No. : 20
 Aerospace Application
 Appl. Axis Code : 7.1.3.1
 Task Performed : DRILLING
 Other Comments : LOCATION SENSING
 Source : AEROSPACE 8/85 P.4

Company ID No. : 18
 Aerospace Application
 Appl. Axis Code : 7.1.3.1
 Task Performed : INSP. AND DERIVET PLANE PARTS
 Other Comments : INTEGRATED SYSTEM
 Source : REPTECH 84 P.115

Company ID No. : 2
 Aerospace Application
 Appl. Axis Code : 7.1.3.2
 Task Performed : DRILLING OF F-16 SHEET PARTS
 Other Comments : TECH MOD. NO LONGER USE TEMPS
 Source : MATRIX 2

Company ID No. : 50
 Aerospace Application
 Appl. Axis Code : 7.1.3.2
 Task Performed : DRILL, RIVET SMALL SUBASSEMBLIES
 Other Comments :
 Source : MATRIX 2

Company ID No. : 20
 Aerospace Application
 Appl. Axis Code : 7.1.4.1
 Task Performed : DRILL, GRIND, INSP COMPSITES
 Other Comments : CASPIN MANTECH PROJECT
 Source : AEROSPACE 8/85 P.4

Company ID No. : 9
 Aerospace Application
 Appl. Axis Code : 7.1.4.2
 Task Performed : DRILL, ROUT, DEBURR C-5B FUSELAGE
 Other Comments : COMB. INCREASES EFFECTIVENESS
 Source : SME MS85-202

Company ID No. : 64
 Non-aerospace Application
 Appl. Axis Code : 7.1.5.1
 Task Performed : PUNCH/PIERCE HOLES IN CAR BODIES
 Other Comments : VISION ASSISTED LOCATION
 Source : ROB TODAY 10/85 P.25

7.0 MATERIAL REDUCTION

8.0 CASTING

Company ID No. : 65
Non-aerospace Application
Appl. Axis Code : 7.1.6.1.1
Task Performed : CUTTING AND DEBURRING
Other Comments : SENSOR ASSISTED, HEAVY LOAD
Source : ROB TODAY 4/85 P.26

Company ID No. : 66
Non-aerospace Application
Appl. Axis Code : 7.1.6.1.2
Task Performed : CLIPPING PCB LEAD ENDS
Other Comments :
Source : MAN ENG 12/85 P.45

Company ID No. : 67
Non-Aerospace Application
Appl. Axis Code : 7.1.6.2.1
Task Performed : LASER MACHINING
Other Comments : NOT IN USE, FOR SALE
Source : MAN ENG 2/85 P.28

Company ID No. : 63
Aerospace Application
Appl. Axis Code : 7.1.6.3.1
Task Performed : WATERJET CUTTING
Other Comments : KEVLAR FABRICATION
Source : MATRIX 2

Company ID No. :
Appl. Axis Code :
Task Performed :
Other Comments :
Source :

Company ID No. :
Appl. Axis Code :
Task Performed :
Other Comments :
Source :

Company ID No. :
Appl. Axis Code :
Task Performed :
Other Comments :
Source :

9.0 FORGING

10.0 MATERIAL HANDLING

Company ID No. : 73
 Aerospace Application
 Appl. Axis Code : 9.0
 Task Performed : FORGE LD/UNLOAD, HOT TRANSFER
 Other Comments : STRAIGHTFORWARD
 Source : ROB TODAY 2/85 P.43

15
 Aerospace Application
 10.1
 MATERIALS HANDLING
 TECHMOD
 MATRIX 2

Company ID No. : 62
 Aerospace Application
 Appl. Axis Code : 9.0
 Task Performed : ISOTHERMAL FORGING CELL
 Other Comments : HEAVY MANTECH/IMIP FUNDING
 Source : MATRIX 2

74
 Aerospace Application
 10.1.1
 REMOVE PART FROM PAINT LINE
 MATRIX 2

Company ID No. : 62
 Aerospace Application
 Appl. Axis Code : 9.1.2
 Task Performed : LOADING COMPRESSOR BLADES
 Other Comments : PART OF AN INTEGRATED SYS.
 Source : ROB TODAY 8.84 P.27

1
 Non-aerospace Application
 10.1.2
 AUTOMATED GUIDED VEHICLE
 MAN ENG 12/85 P.51

Company ID No. :
 Appl. Axis Code :
 Task Performed :
 Other Comments :
 Source :

75
 Non-aerospace Application
 10.1.3
 PLASTIC MOLDING MACH. UNLOAD
 STERLING-DETROIT ROBOT
 ROB TODAY 10/84 P.24

Company ID No. :
 Appl. Axis Code :
 Task Performed :
 Other Comments :
 Source :

29
 Aerospace Application
 10.1.6
 ROBOTIC KITTING
 POLOT GET PRICE, MARK PROGRAM
 AEROSPACE 8/85 P.6

Company ID No. :
 Appl. Axis Code :
 Task Performed :
 Other Comments :
 Source :

29
 Non-aerospace Application
 10.1.7
 LOADING PUNCH PRESS
 LARGE GANTRY ROBOT
 ROB TODAY 8/84 P.25

Company ID No. :
 Appl. Axis Code :
 Task Performed :
 Other Comments :
 Source :

76
 Non-aerospace Application
 10.1.7
 MACHINE LOAD UNLOAD
 LIMITED SENSOR CONTROL
 ROB TODAY 8 84 P.51

9.0 FORGING

10.0 MATERIAL HANDLING

Company ID No. :

Appl. Axis Code :

Task Performed :

Other Comments :

Source :

Company ID No. :

Appl. Axis Code :

Task Performed :

Other Comments :

Source :

Company ID No. :

Appl. Axis Code :

Task Performed :

Other Comments :

Source :

Company ID No. :

Appl. Axis Code :

Task Performed :

Other Comments :

Source :

Company ID No. :

Appl. Axis Code :

Task Performed :

Other Comments :

Source :

Company ID No. :

Appl. Axis Code :

Task Performed :

Other Comments :

Source :

Company ID No. :

Appl. Axis Code :

Task Performed :

Other Comments :

Source :

63

Aerospace Application

10.1.7

TOOL LOAD/UNLOAD (DRILL BITS)

TRANS., INSP, REPLACE, STORAGE

ROB TODAY 12/84 P.37

77

Non-aerospace Application

10.1.7

PRESS LOAD/UNLOAD

SIMPLE PICK AND PLACE

ROB TODAY 2/85 P.38

78

Non-aerospace Application

10.1.7

DUAL ARMED PRESS LOAD/UNLOAD

DUALMATE (TM), SIMULTANEOUS

ROB TODAY 2/85 P.39

79

Non-aerospace Application

10.1.7

SOPHIST. MACH. LOAD/UNLOAD

ORCHRASTED LINE OF MACHS.

MAN ENG 9/84 P.114

80

Non-aerospace Application

10.1.7

MACHINE LOAD/UNLOAD

PRESS LOADING, NO SENSORS

MAN ENG 7/85 P.19

81

Non-aerospace Application

10.1.7

MACHINE LOAD/UNLOAD

PRESSES FOR GRINDING WHEELS

MAN ENG 9/85 P.91

1

Non-aerospace Application

10.1.7

MACHINE LOAD/UNLOAD

ROB TODAY 10/85 P.16

9.0 FORGING

Company ID No. :
 Appl. Axis Code :
 Task Performed :
 Other Comments :
 Source :

Company ID No. :
 Appl. Axis Code :
 Task Performed :
 Other Comments :
 Source :

Company ID No. :
 Appl. Axis Code :
 Task Performed :
 Other Comments :
 Source :

Company ID No. :
 Appl. Axis Code :
 Task Performed :
 Other Comments :
 Source :

Company ID No. :
 Appl. Axis Code :
 Task Performed :
 Other Comments :
 Source :

Company ID No. :
 Appl. Axis Code :
 Task Performed :
 Other Comments :
 Source :

10.0 MATERIAL HANDLING

82
 Non-aerospace Application
 10.1.7
 METAL CUTTING AND FORMING
 ROBOT TOOLCHANGER
 MAN ENG 2/85 P.26

83
 Aerospace Application
 10.1.7
 WAVE SOLDER
 LOADING WAVE SOLDER MACH.
 MATRIX 2

37
 Aerospace Application
 10.1.7
 WAVE SOLDERING OF PC BOARDS
 MATRIX 2

84
 Non-aerospace Application
 10.2.1
 SEMICONDUCTOR WAFER PROC.
 PROCESS MONITORING
 ROB TODAY 8/85 P.14

85
 Non-aerospace Application
 10.2.2
 MACHINE LOAD/UNLOAD GLASS
 DELICATE WORK, HOT GLASS
 ROB TODAY 8/84 P.54

86
 Non-aerospace Application
 10.2.2
 MANUFACTURING THERMOMETERS
 BATHS OF EXTREME TEMPS
 IND ROB 1981 P.12

62
 Aerospace Application
 10.2.2
 HEAT TREAT WORK CELL
 HEAVY MANTECH/IMIP FUNDING
 MATRIX 2

9.0 FORGING

10.0 MATERIAL HANDLING

Company ID No. :
 Appl. Axis Code :
 Task Performed :
 Other Comments :
 Source :

87
 Aerospace Application
 10.2.4
 PICK + PLACE EXPLOSIVES
 JUST GETTING ON LINE
 MATRIX 2

Company ID No. :
 Appl. Axis Code :
 Task Performed :
 Other Comments :
 Source :

3
 Aerospace Application
 10.2.6
 COMPOSITE MATERIAL LAY-UP
 PILOT MANTECH PROGRAM
 AEROSPACE 8/85 P.3

Company ID No. :
 Appl. Axis Code :
 Task Performed :
 Other Comments :
 Source :

39
 Non-aerospace Application
 10.2.7
 DELICATE CERAMIC LOAD/UNLOAD
 ROB TODAY 2/85 P.30

Company ID No. :
 Appl. Axis Code :
 Task Performed :
 Other Comments :
 Source :

88
 Non-aerospace Application
 10.2.7
 PALLETIZING OF GLASS TUBING
 IND ROB 1981 P.11

Company ID No. :
 Appl. Axis Code :
 Task Performed :
 Other Comments :
 Source :

89
 Non-aerospace Application
 10.2.7
 DELICATE MATERIAL HANDLING
 GLASS TV TUBE FACES
 ROB TODAY 10/85 P.16

Company ID No. :
 Appl. Axis Code :
 Task Performed :
 Other Comments :
 Source :

44
 Non-aerospace Application
 10.2.7
 DELICATE MATERIAL HANDLING
 GLASS
 ROB TODAY 4/84 P.42

Company ID No. :
 Appl. Axis Code :
 Task Performed :
 Other Comments :
 Source :

39
 Non-aerospace Application
 10.2.7
 DISKETTE HANDLING
 LOAD/UNLOAD AND PACKAGE
 ROB TODAY 4/84 P.73

9.0 FORGING

Company ID No. :
Appl. Axis Code :
Task Performed :
Other Comments :
Source :

Company ID No. :
Appl. Axis Code :
Task Performed :
Other Comments :
Source :

Company ID No. :
Appl. Axis Code :
Task Performed :
Other Comments :
Source :

Company ID No. :
Appl. Axis Code :
Task Performed :
Other Comments :
Source :

Company ID No. :
Appl. Axis Code :
Task Performed :
Other Comments :
Source :

Company ID No. :
Appl. Axis Code :
Task Performed :
Other Comments :
Source :

Company ID No. :
Appl. Axis Code :
Task Performed :
Other Comments :
Source :

10.0 MATERIAL HANDLING

83
Aerospace Application
10.2.7
STRIPPING COMPONENT LEADS

MATRIX 2

83
Aerospace Application
10.2.7
TINNING COMPONENT LEADS

MATRIX 2

31
Aerospace Application
10.2.7
TINNING COMPONENT LEADS

MATRIX 2

90
Non-aerospace Application
10.2.8
CONCRETE SLAB FINISHER
(CONSTRUCTION)
ROB TODAY 12/85 P.40

APPENDIX E

Current Opportunities Matrix

CURRENT OPPORTUNITIES MATRIX

Overview

	AIRCRAFT	ARMAMENT	BALLISTIC MISSILE	ELECTRONICS	PROPULSION	SPACE
1.0 WELDING	Shaded	Shaded		Shaded	Shaded	
2.0 INSPECTION	Shaded			Shaded	Shaded	
3.0 ASSEMBLY		Shaded		Shaded		
4.0 COATING	Shaded	Shaded		Shaded	Shaded	Shaded
5.0 SEALING/ADHESIVE				Shaded		
6.0 SURFACE PREP	Shaded					
7.0 MATERIAL REDUCTION	Shaded		Shaded		Shaded	
8.0 CASTING	Shaded				Shaded	
9.0 FORGING	Shaded					
10.0 MATERIAL HANDLING	Shaded	Shaded		Shaded	Shaded	

Current Opportunities Matrix

KEY

1.0 Welding	2.0 Inspection	3.0 Assembly	4.0 Painting/Coating	5.0 Sealing/Coating	6.0 Surface Preparation	7.0 Material Reduction	8.0 Casting	9.0 Forging	10.0 Material Handling
E-4		E-5		E-7		E-8		E-10	
		E-6				E-9			

NOTE: The following pages may be arranged in the order shown to display the entire matrix.

1.0 WELDING

2.0 INSPECTION

Company ID No. : 32
 Current Opport. : WELDING
 Appl. Axis Code : 1.0
 Desired Advantages:

1
 CIRCUIT BOARD TEST
 2.3

Company ID No. : 61
 Current Opport. : WELDING
 Appl. Axis Code : 1.0
 Desired Advantages:

1
 ODD COMPONENT INSPECTION
 2.3

Company ID No. : 15
 Current Opport. : WELDING
 Appl. Axis Code : 1.0
 Desired Advantages: INCREASED QUALITY

Company ID No. : 91
 Current Opport. : ARC WELDING
 Appl. Axis Code : 1.1
 Desired Advantages:

Company ID No. :
 Current Opport. :
 Appl. Axis Code :
 Desired Advantages:

Company ID No. :
 Current Opport. :
 Appl. Axis Code :
 Desired Advantages:

Company ID No. :
 Current Opport. :
 Appl. Axis Code :
 Desired Advantages:

Company ID No. :
 Current Opport. :
 Appl. Axis Code :
 Desired Advantages:

Company ID No. :
 Current Opport. :
 Appl. Axis Code :
 Desired Advantages:

3.0 ASSEMBLY

4.0 PAINTING/COATING

Company ID No. : 32
 Current Opport. : ASSEMBLY
 Appl. Axis Code : 3.0
 Desired Advantages:

3
 PAINTING
 4.1
 45% ROI, INCREASED THRPT

Company ID No. : 63
 Current Opport. : WIRE WRAPPING
 Appl. Axis Code : 3.1
 Desired Advantages: 40% INCREASED THROUGHPUT

63
 SMALL PARTS PAINTING
 4.1

Company ID No. : 50
 Current Opport. : SMALL PART ASSEMBLY
 Appl. Axis Code : 3.1
 Desired Advantages: INCREASE IN S/M CAPABILITY

63
 MEDIUM PARTS PAINTING
 4.1

Company ID No. : 1
 Current Opport. : "BLACK BOX" ASS'Y
 Appl. Axis Code : 3.1
 Desired Advantages:

63
 FINAL PAINT PROCESS
 4.1

Company ID No. : 91
 Current Opport. : WIRE HARNESS ASS'Y
 Appl. Axis Code : 3.1
 Desired Advantages:

92
 CIRCUIT BOARD MASKING
 4.1

Company ID No. : 74
 Current Opport. : EXPLOSIVE UNIT ASS'Y
 Appl. Axis Code : 3.1
 Desired Advantages:

61
 ROBOTIC PAINTING
 4.1

Company ID No. : 61
 Current Opport. : LIGHT ASS'Y
 Appl. Axis Code : 3.1
 Desired Advantages:

16
 SPRAY PAINTING
 4.1

Company ID No. : 12
 Current Opport. : COMPOSITE ASS'Y AND FAB.
 Appl. Axis Code : 3.1
 Desired Advantages: INCREASED QUAL., DECR. COST

83
 DIP COMPONENTS FOR TINNING
 4.2

Company ID No. : 1
 Current Opport. : GYRO ASSEMBLY (CLEAN ROOM)
 Appl. Axis Code : 3.2
 Desired Advantages:

93
 SPARY COATING
 4.2
 3X INCREASED ROI

3.0 ASSEMBLY

Company ID No. : 61
Current Opport. : PC BOARD ASS'Y
Appl. Axis Code : 3.2
Desired Advantages:

Company ID No. :
Current Opport. :
Appl. Axis Code :
Desired Advantages:

Company ID No. :
Current Opport. :
Appl. Axis Code :
Desired Advantages:

Company ID No. :
Current Opport. :
Appl. Axis Code :
Desired Advantages:

Company ID No. :
Current Opport. :
Appl. Axis Code :
Desired Advantages:

Company ID No. :
Current Opport. :
Appl. Axis Code :
Desired Advantages:

Company ID No. :
Current Opport. :
Appl. Axis Code :
Desired Advantages:

Company ID No. :
Current Opport. :
Appl. Axis Code :
Desired Advantages:

Company ID No. :
Current Opport. :
Appl. Axis Code :
Desired Advantages:

4.0 PAINTING/COATING

3
SOLDERING OF MAGNETS
4.2
ROI BOOSTED, INCR. THRPT

1
TINNING COMPONENTS
4.2

94
PLASMA ARC METAL SPRAYING
4.2.7
REDUCED COST, INCR. CAP

5.0 SEALING/ADHESIVE

6.0 SURFACE PAREPARATION

Company ID No. :	63
Current Opport. :	BRUSH DEBURRING
Appl. Axis Code :	6.1
Desired Advantages:	40% ROI, INCR. THRPT
Company ID No. :	63
Current Opport. :	LARGE PART DEBURRING
Appl. Axis Code :	6.1
Desired Advantages:	
Company ID No. :	63
Current Opport. :	SHEET STOCK DEBURR
Appl. Axis Code :	6.1
Desired Advantages:	
Company ID No. :	63
Current Opport. :	PLASTIC EDGE GRINDING
Appl. Axis Code :	6.1
Desired Advantages:	
Company ID No. :	63
Current Opport. :	FIBER WOUND PLASTIC DEBURR
Appl. Axis Code :	6.1
Desired Advantages:	
Company ID No. :	63
Current Opport. :	MACHINE PART DEBURR
Appl. Axis Code :	6.1
Desired Advantages:	
Company ID No. :	
Current Opport. :	
Appl. Axis Code :	
Desired Advantages:	
Company ID No. :	
Current Opport. :	
Appl. Axis Code :	
Desired Advantages:	

7.0 MATERIAL REDUCTION

8.0 CASTING

Company ID No. : 12
 Current Opport. : SHEET METAL FABRICATION
 Appl. Axis Code : 7.0
 Desired Advantages: INCR. QUAL, DECR. COST

Company ID No. : 95
 Current Opport. : BARBERING STATION
 Appl. Axis Code : 7.1
 Desired Advantages: ELIM. OF SKILLED LABOR

Company ID No. : 74
 Current Opport. : MILLING
 Appl. Axis Code : 7.1.1
 Desired Advantages:

Company ID No. : 63
 Current Opport. : ROUTING
 Appl. Axis Code : 7.1.2
 Desired Advantages: 40% ROI, INCR. THRPT.

Company ID No. : 50
 Current Opport. : ROUTING
 Appl. Axis Code : 7.1.2
 Desired Advantages: HIGH PAYBACK, RED. COST

Company ID No. : 74
 Current Opport. : ROUTING
 Appl. Axis Code : 7.1.2
 Desired Advantages:

Company ID No. : 9
 Current Opport. : LARGE ROUTING W/O TEMP.
 Appl. Axis Code : 7.1.2
 Desired Advantages: DECR. COST, INCR. QUAL/THRPT

Company ID No. : 50
 Current Opport. : DRILLING
 Appl. Axis Code : 7.1.3
 Desired Advantages: HIGH PAYBACK, REDUCED COST

Company ID No. : 74
 Current Opport. : DRILLING
 Appl. Axis Code : 7.1.3
 Desired Advantages:

63
 STURCTURAL CASTING
 8.1
 40% ROI, INCR. THRPT

63
 PLASTIC MOLDING
 8.2
 40% ROI, INCR. THRPT

96
 PLASTIC MOLDING
 8.2

7.0 MATERIAL REDUCTION

8.0 CASTING

Company ID No. : 9
Current Opport. : DRILLING W/O TEMPLATE
Appl. Axis Code : 7.1.3
Desired Advantages: DECR. COST, INCR. QUAL

Company ID No. : 61
Current Opport. : LASER DRILLING
Appl. Axis Code : 7.1.6.2
Desired Advantages:

Company ID No. : 63
Current Opport. : WATER JET CUTTING
Appl. Axis Code : 7.1.6.3
Desired Advantages: 40% ROI, INCR. THRPT

Company ID No. : 63
Current Opport. : WATER JET CUTTING
Appl. Axis Code : 7.1.6.3
Desired Advantages:

Company ID No. :
Current Opport. :
Appl. Axis Code :
Desired Advantages:

Company ID No. :
Current Opport. :
Appl. Axis Code :
Desired Advantages:

Company ID No. :
Current Opport. :
Appl. Axis Code :
Desired Advantages:

Company ID No. :
Current Opport. :
Appl. Axis Code :
Desired Advantages:

Company ID No. :
Current Opport. :
Appl. Axis Code :
Desired Advantages:

9.0 FORGING

10. MATERIAL HANDLING

Company ID No. : 63
 Current Opport. : HOT DIE FORMING
 Appl. Axis Code : 9.2
 Desired Advantages:

61
 MATERIAL HANDLING
 10.0

Company ID No. : 63
 Current Opport. : AUTOMATED TUBE BENDING
 Appl. Axis Code : 9.2.10
 Desired Advantages: 40% ROI, INCR. THRPT.

15
 MATERIAL HANDLING
 10.0

Company ID No. :
 Current Opport. :
 Appl. Axis Code :
 Desired Advantages:

93
 PALLETIZING
 10.1
 3X INCR. ROI, THRPT

Company ID No. :
 Current Opport. :
 Appl. Axis Code :
 Desired Advantages:

62
 MATERIAL HANDLING (DISK MFG)
 10.1

Company ID No. :
 Current Opport. :
 Appl. Axis Code :
 Desired Advantages:

74
 EXPLOSIVE MATERIAL HANDLING
 10.2.4

Company ID No. :
 Current Opport. :
 Appl. Axis Code :
 Desired Advantages:

87
 EXPLOSIVE MATERIAL HANDLING
 10.2.4
 REMOVAL OF PERSONNEL

Company ID No. :
 Current Opport. :
 Appl. Axis Code :
 Desired Advantages:

12
 COMPOSITE ASS'Y AND FAB.
 10.2.6
 INCR. QUAL, DECR. COST

Company ID No. :
 Current Opport. :
 Appl. Axis Code :
 Desired Advantages:

Company ID No. :
 Current Opport. :
 Appl. Axis Code :
 Desired Advantages:

APPENDIX F

Future Opportunities Matrix

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AEROSPACE ROBOTIC IMPLEMENTATIONS: AN ASSESSMENT AND
FORECAST PHASE 2(U) DHR INC MCLEAN VA F C BROOKS
SEP 86 F33657-85-D-0111

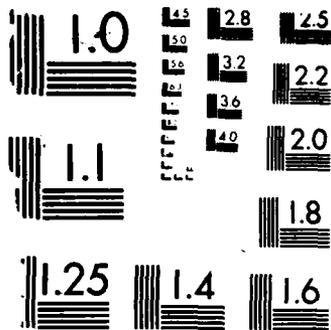
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MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963-A

FUTURE OPPORTUNITIES MATRIX

Overview

	AIRCRAFT	ARMAMENT	BALLISTIC MISSILE	ELECTRONICS	PROPULSION	SPACE
1.0 WELDING						
2.0 INSPECTION						
3.0 ASSEMBLY						
4.0 COATING						
5.0 SEALING/ADHESIVE						
6.0 SURFACE PREP						
7.0 MATERIAL REDUCTION						
8.0 CASTING						
9.0 FORGING						
10.0 MATERIAL HANDLING						

Future Opportunities Matrix

KEY

1.0 Welding	2.0 Inspection	3.0 Assembly	4.0 Painting/Coating	5.0 Sealing/Adhesive	6.0 Surface Preparation	7.0 Material Reduction	8.0 Casting	9.0 Forging	10.0 Material Handling
F-4		F-5		F-7		F-8		F-9	
		F-6							

NOTE: The following pages may be arranged in the order shown to display the entire matrix.

1.0 WELDING

2.0 INSPECTION

Company ID No. :
 Future Opport. :
 Appl. Axis Code :
 Desired Advantages:
 Barriers to Imp. :

61
 AUTOMATED INSPECTION
 2.0
 FUNDING

Company ID No. :
 Future Opport. :
 Appl. Axis Code :
 Desired Advantages:
 Barriers to Imp. :

56
 AUTO. INSP. AND TEST
 2.3
 ROI WOULD INCREASE
 FUNDING

Company ID No. :
 Future Opport. :
 Appl. Axis Code :
 Desired Advantages:
 Barriers to Imp. :

Company ID No. :
 Future Opport. :
 Appl. Axis Code :
 Desired Advantages:
 Barriers to Imp. :

Company ID No. :
 Future Opport. :
 Appl. Axis Code :
 Desired Advantages:
 Barriers to Imp. :

Company ID No. :
 Future Opport. :
 Appl. Axis Code :
 Desired Advantages:
 Barriers to Imp. :

Company ID No. :
 Future Opport. :
 Appl. Axis Code :
 Desired Advantages:
 Barriers to Imp. :

Company ID No. :
 Future Opport. :
 Appl. Axis Code :
 Desired Advantages:
 Barriers to Imp. :

3.0 ASSEMBLY

4.0 PAINTING/COATING

Company ID No. : 56
 Future Opport. : ASS'Y OF PC BOARDS
 Appl. Axis Code : 3.0
 Desired Advantages: INCREASED THRPT, S/M CAPAB.
 Barriers to Imp. : FUNDING

3
 DEPAINTING
 4.1
 48% ROI
 FUNDING

Company ID No. : 63
 Future Opport. : WIRE HARNESS ASS'Y
 Appl. Axis Code : 3.1
 Desired Advantages:
 Barriers to Imp. :

56
 SOLDERING
 4.1
 INCR. THRPT, S/M CAPAB.
 FUNDING

Company ID No. : 63
 Future Opport. : CANOPY ASS'Y
 Appl. Axis Code : 3.1
 Desired Advantages:
 Barriers to Imp. :

Company ID No. : 61
 Future Opport. : SMALL PART ASS'Y
 Appl. Axis Code : 3.1
 Desired Advantages:
 Barriers to Imp. : FUNDING

Company ID No. : 87
 Future Opport. : ASS'Y OF EXPLOSIVE UNITS
 Appl. Axis Code : 3.1
 Desired Advantages: REMOVAL OF PERSONNEL
 Barriers to Imp. : TECHNOLOGY CERTIFICATION

Company ID No. : 9
 Future Opport. : FINAL ASS'Y
 Appl. Axis Code : 3.1
 Desired Advantages:
 Barriers to Imp. :

Company ID No. : 40
 Future Opport. : HYBRID CIRCUIT ASS'Y
 Appl. Axis Code : 3.2
 Desired Advantages:
 Barriers to Imp. : FUNDING

Company ID No. : 4C
 Future Opport. : PC BOARD ASS'Y
 Appl. Axis Code : 3.2
 Desired Advantages:
 Barriers to Imp. : FUNDING

3.0 ASSEMBLY

Company ID No. : 3
Future Opport. : RIVETING
Appl. Axis Code : 3.3.1
Desired Advantages: 60% ROI, INCR. THRPT
Barriers to Imp. : FUNDING

Company ID No. : 63
Future Opport. : RIVET INSERTION
Appl. Axis Code : 3.3.1
Desired Advantages: 40% ROI, INCR. THRPT
Barriers to Imp. :

63
Company ID No. : SMALL STRUCTURE RIVETING
Future Opport. : 3.3.1
Appl. Axis Code :
Desired Advantages:
Barriers to Imp. :

63
Company ID No. : LARGE STRUCTURE RIVETING
Future Opport. : 3.3.1
Appl. Axis Code :
Desired Advantages:
Barriers to Imp. :

Company ID No. :
Future Opport. :
Appl. Axis Code :
Desired Advantages:
Barriers to Imp. :

Company ID No. :
Future Opport. :
Appl. Axis Code :
Desired Advantages:
Barriers to Imp. :

Company ID No. :
Future Opport. :
Appl. Axis Code :
Desired Advantages:
Barriers to Imp. :

Company ID No. :
Future Opport. :
Appl. Axis Code :
Desired Advantages:
Barriers to Imp. :

4.0 PAINTING/COATING

5.0 SEALING/ADHESIVE

6.0 SURFACE PREPARATION

Company ID No. : 50
 Future Opport. : SEALING OF WING SURFACES
 Appl. Axis Code : 5.3
 Desired Advantages: VERY HIGH ROI
 Barriers to Imp. : TIME

63
 COUTOUR ROLL FORMING
 6.4.2
 40% ROI, INCR. THRPT.

Company ID No. :
 Future Opport. :
 Appl. Axis Code :
 Desired Advantages:
 Barriers to Imp. :

3
 CANOPY POLISHING
 6.5
 38% ROI, INCR. THRPT.
 FUNDING

Company ID No. :
 Future Opport. :
 Appl. Axis Code :
 Desired Advantages:
 Barriers to Imp. :

Company ID No. :
 Future Opport. :
 Appl. Axis Code :
 Desired Advantages:
 Barriers to Imp. :

Company ID No. :
 Future Opport. :
 Appl. Axis Code :
 Desired Advantages:
 Barriers to Imp. :

Company ID No. :
 Future Opport. :
 Appl. Axis Code :
 Desired Advantages:
 Barriers to Imp. :

Company ID No. :
 Future Opport. :
 Appl. Axis Code :
 Desired Advantages:
 Barriers to Imp. :

Company ID No. :
 Future Opport. :
 Appl. Axis Code :
 Desired Advantages:
 Barriers to Imp. :

7.0 MATERIAL REDUCTION

8.0 CASTING

Company ID No. : 63
 Future Opport. : ADVANCED MACHINING PROCESSES
 Appl. Axis Code : 7.1
 Desired Advantages: 40% ROI, INCR. THRPT.
 Barriers to Imp. : CONTROL TECHNOLOGY, FUNDING

Company ID No. : 62
 Future Opport. : TURBINE BLADE FINISHING
 Appl. Axis Code : 7.1
 Desired Advantages: REDUCED COST
 Barriers to Imp. : FUNDING

Company ID No. : 16
 Future Opport. : HOLE DRILLING
 Appl. Axis Code : 7.1.3
 Desired Advantages: INCREASED QUALITY
 Barriers to Imp. : MORE ACCURATE TECHNOLOGY

Company ID No. :
 Future Opport. :
 Appl. Axis Code :
 Desired Advantages:
 Barriers to Imp. :

Company ID No. :
 Future Opport. :
 Appl. Axis Code :
 Desired Advantages:
 Barriers to Imp. :

Company ID No. :
 Future Opport. :
 Appl. Axis Code :
 Desired Advantages:
 Barriers to Imp. :

Company ID No. :
 Future Opport. :
 Appl. Axis Code :
 Desired Advantages:
 Barriers to Imp. :

Company ID No. :
 Future Opport. :
 Appl. Axis Code :
 Desired Advantages:
 Barriers to Imp. :

9.0 FORGING

10.0 MATERIAL HANDLING

<p>Company ID No. : Future Opport. : Appl. Axis Code : Desired Advantages: Barriers to Imp. :</p>	<p>74 EXPLOSIVE MATERIAL HANDLING 10.2.4 SAFETY, REMOVAL OF PERSONNEL SAFETY REQUIREMENTS</p>
<p>Company ID No. : Future Opport. : Appl. Axis Code : Desired Advantages: Barriers to Imp. :</p>	<p>63 FILAMENT WOUND COMPOSITES 10.2.6 INCREASED THROUGHPUT</p>
<p>Company ID No. : Future Opport. : Appl. Axis Code : Desired Advantages: Barriers to Imp. :</p>	<p>74 COMPOSITE WINDING 10.2.6</p>
<p>Company ID No. : Future Opport. : Appl. Axis Code : Desired Advantages: Barriers to Imp. :</p>	<p>61 COMPOSITE TAPE LAYUP 10.2.6 FUNDING</p>
<p>Company ID No. : Future Opport. : Appl. Axis Code : Desired Advantages: Barriers to Imp. :</p>	
<p>Company ID No. : Future Opport. : Appl. Axis Code : Desired Advantages: Barriers to Imp. :</p>	
<p>Company ID No. : Future Opport. : Appl. Axis Code : Desired Advantages: Barriers to Imp. :</p>	
<p>Company ID No. : Future Opport. : Appl. Axis Code : Desired Advantages: Barriers to Imp. :</p>	

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