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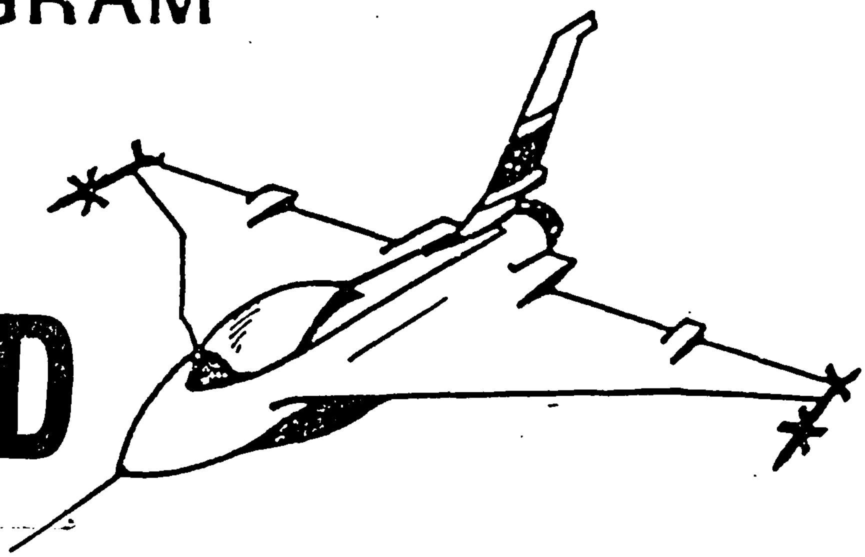

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FINAL TECHNICAL REPORT
CATEGORY II PROJECT
LASER SOLDER/INSPECTION

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MARCH 1, 1985

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The purpose of this project is to investigate the feasibility of laser solder/inspection.

The following areas 1) solder applicator for dispensing solder on a joint 2) laser for pulsing each joint with radiant heat 3) instrument for detecting acceptable/defective joints 4) a computer based system for monitoring and controlling activities will be analyzed to create a closed loop network which will solder each joint individually and verify defective joints.

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CATEGORY II PROJECT
LASER SOLDER/INSPECTION
TRACOR PROJECT 560

March 1, 1985

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LASER SOLDER/INSPECTION

ABSTRACT

This final report covers the work performed on the Laser Solder/Inspection Project performed in conjunction with Tracor Aerospace's Industrial Tech Mod Program for General Dynamics, Program Administrators for the F-16 SPO. The work described herein discusses the results of some one thousand engineering hours and the technical and economic issues which resulted in an early termination of the project. Based on the available technical data and preliminary cost benefit analysis, the integration of laser soldering with laser inspection is not a practical alternative to processing printed wiring boards in an industry where small to medium production quantities are produced to standard military requirements.

1.0 INTRODUCTION AND SUMMARY

The primary objective of the Laser Solder/Inspection Project was to investigate and, if feasible, develop from commercially available hardware a new manufacturing process for soldering electronic components onto Printed Wiring Boards (PWB) and inspecting each joint for compliance to military standards. The system consists of four major subsystems: 1) a solder applicator for dispensing solder on a joint, 2) a laser for pulsing each joint with radiant heat, 3) an instrument for detecting acceptable/defective joints, and 4) a computer-based system for monitoring and controlling all activities. The task was to integrate these subsystems into a closed loop network which would solder each joint individually, verify the integrity of the bond and document defective joints.

During the first six months, Tracor gathered and synthesized technical information from laser system suppliers, solder application vendors, and end users of laser solder systems and laser inspection systems. Paralleling these activities was an in-house evaluation of current and proposed production requirements. Consolidating both the technical information with the in-house production requirements, Tracor was able to produce the system requirements and complete an early assessment of the project's feasibility. Tracor has concluded that the technology required to integrate laser solder with laser inspection is not doable or a cost effective alternative to processing leaded component electronic assemblies of standard reliable products.

2.0 PROGRAM PLAN AND TECHNICAL APPROACH

At the on start of the project the proposed work plan was reviewed and updated to reflect current thinking. A systematic work plan and technical approach, composed of several tasks, was developed to meet program objectives of integrating, prototyping, and implementing a laser solder/inspection system. Establishing the performance requirements for a laser solder/inspection system through research of acceptable practices and vendor evaluations was the first task. During this effort issues such as defining acceptable levels of quality, operating parameters, setup and solder/inspect cycle times, system reliability levels and communication interface requirements were planned.

Following this task, Tracor planned to validate the proposed concept and/or modify it to agree with gained knowledge. Extensive consultation with outside vendors would address specific issues such as solder application, feedback control, and hardware mechanics. Potential vendors were expected to conduct a proof-of-concept demonstration. This demonstration would validate the state-of-the-art and provide a realistic assessment of the vendor's qualifications/capabilities to perform prototype and integration tasks.

A cost benefit analysis was planned to parallel the technical evaluation. This analysis would refine information gathered during Phase I and present detailed cost/savings resulting from the project.

Following satisfactory technical evaluations, risk assessments, and cost benefit analysis, equipment and system specifications would be prepared and submitted to qualified vendors. These specifications would convey as a minimum:

- System requirements
- Hardware/software interface requirements
- Performance requirements
- Human factor considerations

Solicited vendors would respond with hardware/software development plans and implementation strategy. Major development milestones related to prototype fabrication and integration would also be included. Tracor technical personnel would review each proposal and make an evaluation of the vendor's ability to modify his off-the-shelf equipment to Tracor's specifications. Those vendors demonstrating technical competence and cost competitiveness would be selected. These vendors would modify their hardware and work closely with in-house personnel to assure system compatibility. After successfully completing vendor testing and qualification, the individual system components would be brought in-house for integration and qualification.

A series of in-house evaluations would be made after assembling the system to assess the impact on direct labor and validate the integrated laser solder/inspection system in a production line environment. During this evaluation, industrial engineering practices would be employed to verify performance results. Process cost, direct/indirect labor savings, material savings, and utility reductions would be measured and compared against projected savings. Also during qualifications the laser solder/inspection system would undergo a correlation testing program to verify the system as an acceptable process for military products. Correlation between laser solder/inspection system acceptable/rejectable joints and military standards would be documented and used to solicit acceptance of laser soldering/laser inspection by the appropriate procurement agencies. Conclusions reached during this task would provide the grounds for expanding or limiting the use of the system for military printed wiring board assemblies.

Acceptance and approval by the procurement agencies would release the system for general production use. Operation procedures, process instructions documentation on control software would be prepared and presented as part of a final report. The final report would also contain the results of the project to include:

- Technical requirements
- Final cost benefit analysis
- Test - evaluation - qualification results
- System hardware/software drawings or schematics
- Other documentation as required

3.0 PROPOSED CONCEPT

The proposed concept(s) called for the laser solder/inspection project to integrate major components, commercially available and off-the-shelf, into a system which would solder and inspect individual joints. Major components included

- Solder applicator
- Heat applicator (laser)
- Infrared detector
- Computer-based position and control system

Figures 1 through 3 represent conceptual sketches of the proposed system. The noted cell would receive printed wiring boards in batch form from either a production control stockroom or directly from the Printed Wiring Board assembly area. Boards would be presented to an area within the cell where soldering would be performed by dispensing solder and impinging the joint with the proper amount of laser heat. Following the solder operation, the board would be repositioned to a laser inspection area. Here a laser working in conjunction with an infrared detector would obtain a signature of each joint. Correlation of each joint's signature would be made against a standard and the results documented. Statistical data would be retained for use in subsequent sampling routines. Defective joints would be documented and the corresponding data used for joint repair. Finished boards would be grouped and batched to the next process.

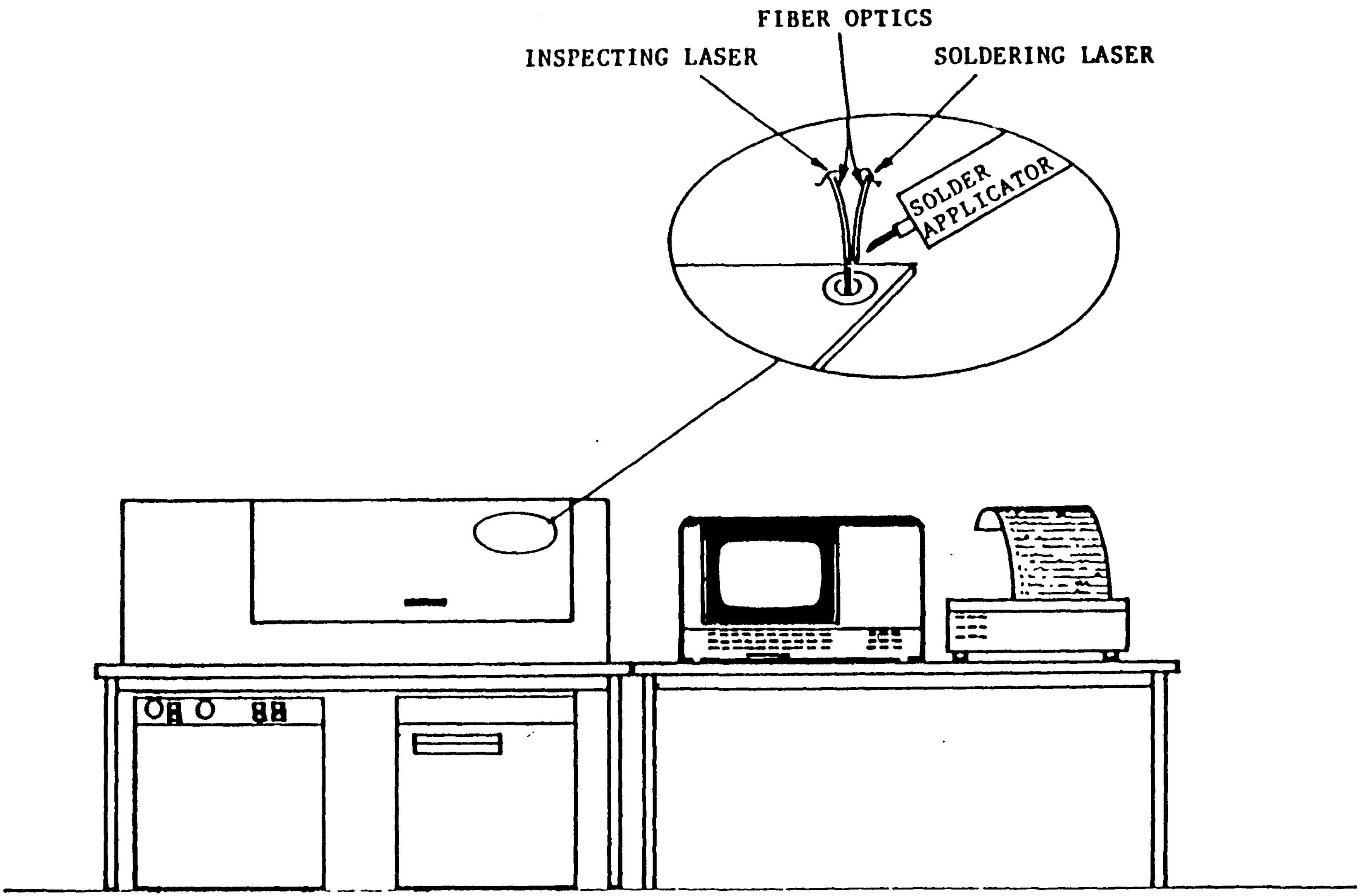

Figure 1

PWA LASER SOLDERING/INSPECTION
DESIGN CONCEPT NO. 1

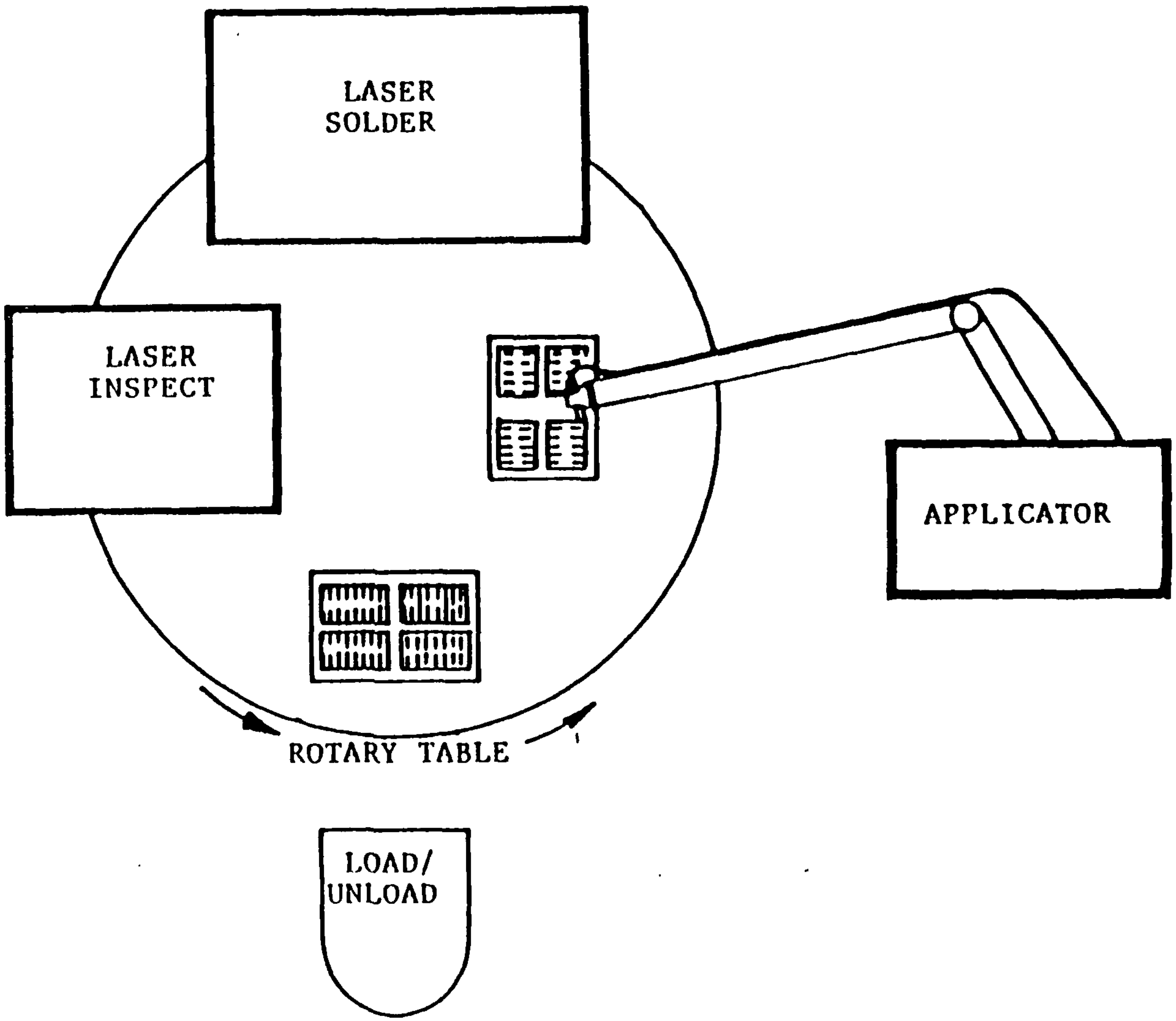

Figure 2

PWA LASER SOLDERING/INSPECTION
DESIGN CONCEPT No. 2

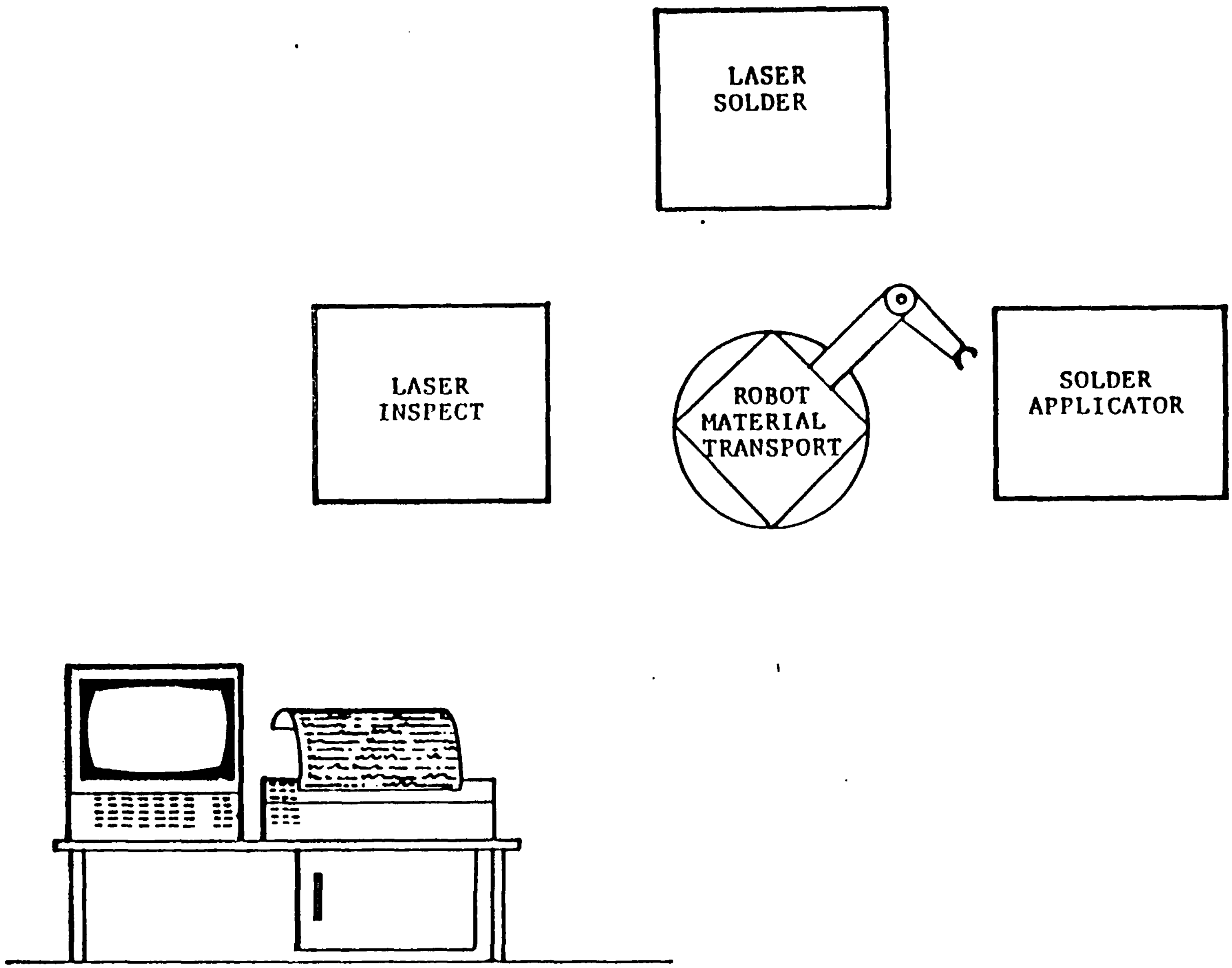

Figure 3

PWA LASER SOLDERING/INSPECTION
DESIGN CONCEPT NO. 3

4.0 SYSTEM REQUIREMENTS

Considerable involvement by industry leaders, research institutions, and in-house technical personnel was necessary to develop the system requirements for the solder application, laser solder, laser inspection, and configuration control.

4.1 Solder Application Requirements

Three methods were investigated as viable methods to apply solder to the joints. Each method is currently used by industry and offers advantages and disadvantages depending on board configuration, type of components and soldering system. In the first method, each joint or pad (both sides of the board) is overplated with solder during board processing. In the second case, a solder paste or cream is applied to the joint prior to soldering. The third method, similar to wire feed welding, dispenses a controlled amount of solder wire during the laser soldering process. This third method was initially proposed and was at that time the preferred method. Reasons for its selection were 1) Engineering did not have to revise drawings, 2) pre-secondary operations were not required, and 3) the operation of dispensing the solder could occur at the time of lasing. However, as Tracor's understanding of the process improved, relative to the system requirements and specifications, the approach was found to have several limitations and major drawbacks. These restraints were:

1) The physical placement of the wire into the focused beam.

2) The interference of the wire with close proximity components and failure to maintain a proper angle of attack.

3) The inability of the system to maintain controlled cycle rates compatible with the absorption of laser radiation.

4) The ductility of solder causes the small diameter wire to yield under mechanical pressures.

In light of these discoveries, the method of feeding the solder during lasing was discarded for the overplating method. This method was selected over the solder paste or cream method for several reasons. The overplating process eliminated the need to establish secondary operations requiring additional facilities, overhead and labor. Secondly, the process of depositing tin-lead alloy and plating printed wiring boards is a proven technology and inherent to the current method of processing boards. The stringent process controls adhered to by the vendors results in board consistency and high quality. Thirdly, the process requirements are easily established since only the engineering drawings and vendor process specifications need to be modified to permit three to four times the additional solder on each pad, both sides of the board.

4.2 Laser Soldering

The system requirements for laser soldering reflected the need for a real-time, closed loop system which would monitor and control 1) board position to X, Y datums and Z planes, 2) cycle times, and 3) thermal rise and decay of the laser pulse. Within this broad range of requirements, a more exhaustive list was prepared. During the investigative analysis a review of commercial available laser soldering systems was performed. The systems which have emerged as the most suitable for soldering applications are the Carbon Dioxide Laser (CO_2) and Neodymium Laser (YAG). Both systems can be operated in a continuous mode and can interface with computer positioning systems. Also, both systems have an operating cost of approximately one dollar per hour.

The process of laser soldering is similar to laser inspection; the difference is the amount of laser energy applied at the focused point and the exposure time, typically 3-4 times longer. With the CO_2 laser the beam is produced by flowing a mixture of carbon dioxide, helium, and nitrogen gases through an optical resonator and applying high voltage across the mixture which causes the lasing to occur. This produces an invisible beam of infrared light energy at 10.6 microns. The YAG laser is similar to the CO_2 laser; however, lasing occurs by stimulating certain glasses, in particular a Yttrium Aluminum Garnet (YAG), by an arc lamp. The light is amplified or "pumped" to a suitable intensity where the light is permitted to escape from one of two polished aluminum reflectors.

Figures 4 and 5 show typical system configurations for laser soldering. Both systems consist of the basic laser with an associated power supply and water cooling system, an objective lens to focus the beam to a suitable spot diameter and some means of positioning the part to be processed under the beam. Since both laser beams are invisible, some means of beam position and focal point indication is necessary.

Characteristics of the two systems are shown in Table 1. While the YAG laser has a slight advantage over the CO_2 laser in terms of laser absorption qualities, the CO_2 laser can

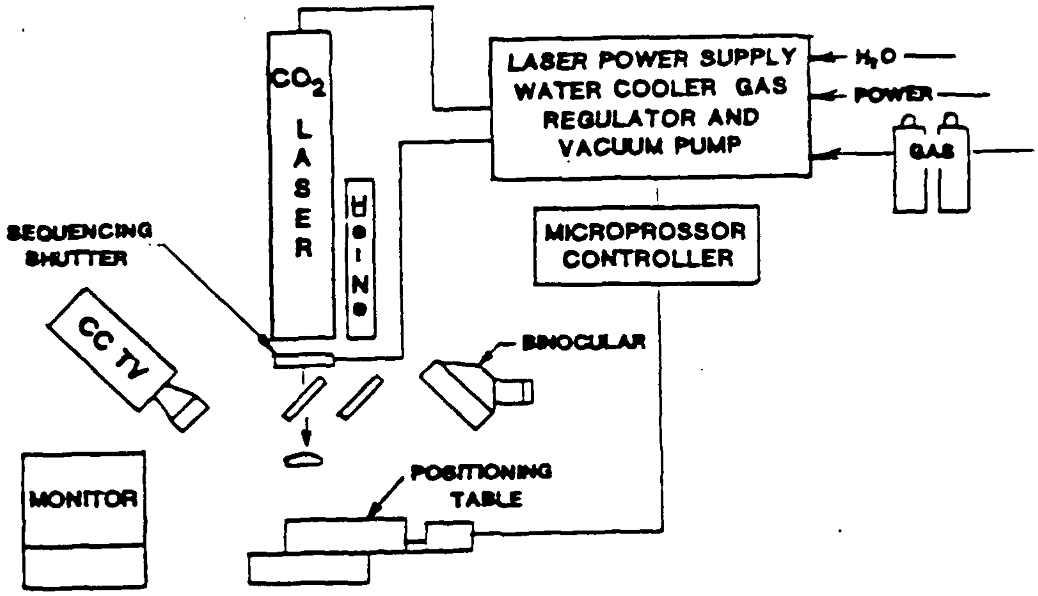

Figure 4. Typical CO_2

Reflow Soldering System

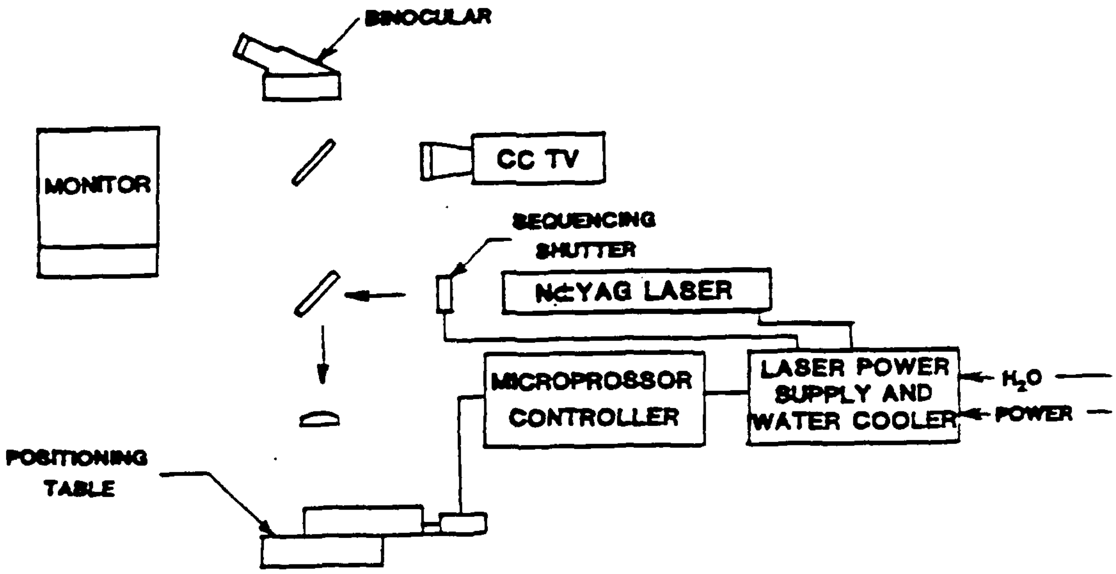

Figure 5. Typical Nd:YAG

Reflow Soldering System

be adjusted to provide a pulse rate which has a gradual power curve. The resultant evaluation reflected that the most appropriate laser for soldering would be a CO_2 laser with dynamic power adjustment.

TABLE 1. CHARACTERISTICS OF CO_2 AND YAG LASERS

	CO_2 LASER	YAG LASER
Wave Length	10.6 Micrometer	1.06 Micrometer
Absorption	Insulated Materials	Conductive Metals
Operation Mod	Pulsed	Continuous
Viewing and Rows	Off-Axis Binocular	Coaxial
Output Power	Variable	Fixed
Laser Media	CO_2 Gas	Yttrium Aluminum Garnet

The following specific requirements were developed for the laser soldering system. The power range should be adjustable within 15 to 75 watts (75 watts max continuous duty). This would provide a suitable range to solder various leaded components and also be adaptable for use on other applications such as:

- Soldering edge-connector fingers
- Trim excess material from resistive and capacitive mask
- Wire stripping insulation away from metal conductors
- Engrave serial numbers on component frames
- Scribe, cut or drill ceramic substrates

The laser focal lens should be capable of producing a focused beam of .0035 inches diameter. To aid in beam positioning, a helium-neon laser is required to precisely define spot location. For control and monitoring of the system activities, the laser soldering computer should be a 256K Byte machine configured as a micro or minicomputer and contain two (2) floppy disc drives, CRT monitor, alpha-numeric keyboard and RS 232/RS 422 interface parts. The system should allow for quick and easy programming of printed wiring boards. The system should also contain a dot matrix printer for outputting statistical data on system performance and discrepancies. The positioning system should permit the processing of printed wiring boards from 2 inches square to 18 inches square and be capable of indexing .025 inches in 500 milliseconds.

4.3 Laser Inspection

The system requirements for laser inspection were based on the availability of only one commercial system, the Laser/INSPECT system developed by Vanzetti Systems, Inc. The company currently holds all patent rights for laser inspection of solder joints. The system checks the integrity of each joint by pulsing it with a millisecond burst of radiation from a Neodymium - YAG laser. Its operation is based on the transfer characteristics of heat through a solder joint. If a specific amount of controlled heat is applied to a joint, it will travel through the joint at a certain rate. The presence of defects (e.g., voids, cracks, inclusions, corrosion, etc.) at any point along the heat diffusion path alters the transfer rate. The delta between an "ideal" and "defective" joint can be measured through the use of an infrared sensor. This infrared sensor measures the thermal rise and decay of the joint and correlates the readings to a thermal signature. This thermal signature is a function of the joint's characteristics (see Figure 6) and flags joints which deviate beyond prescribed thresholds.

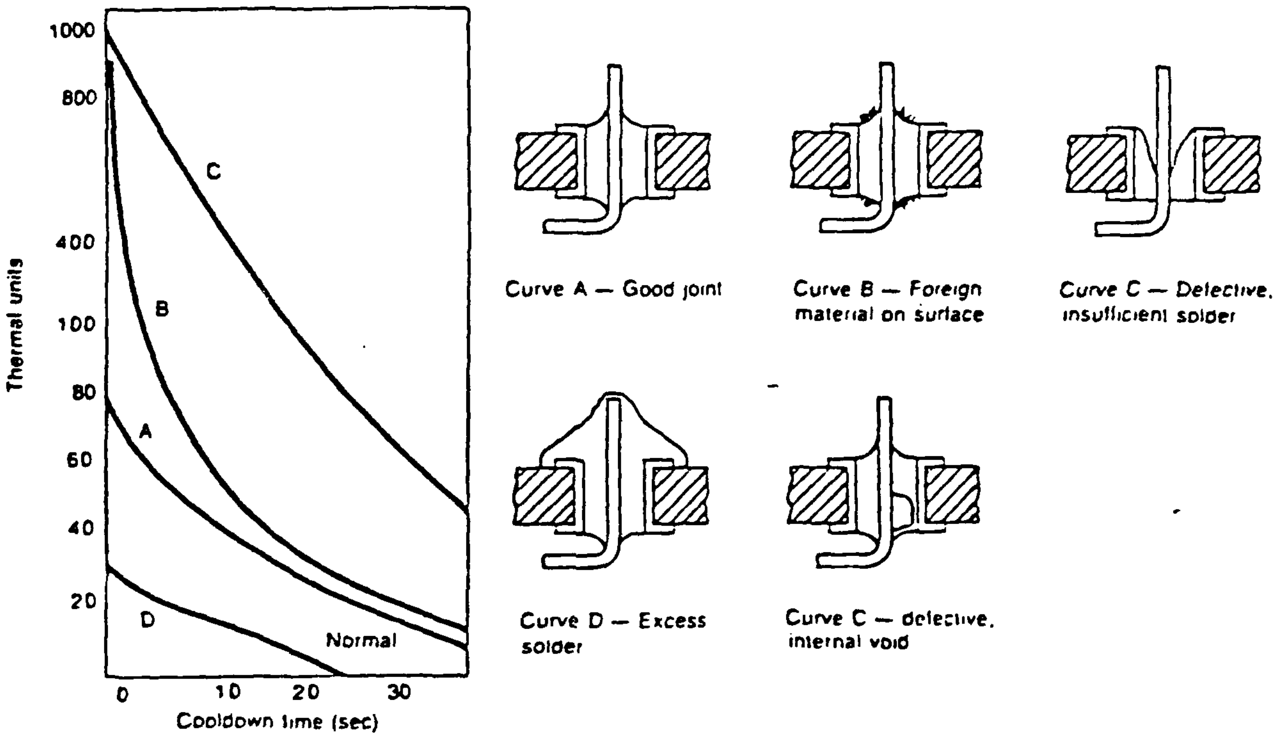

Figure 6. Representative Thermal Signatures and Corresponding Joint Characteristic

The system requirements for the laser soldering system are basically those published. However, the control system should provide for quick and easy programming of printed wiring boards between 2 inches square and 18 inches square. In addition, Tracor recommends that the computer be increased to a 256K Byte machine configured as a micro or minicomputer and contain two (2) floppy disc drives, CRT monitor, alpha-numeric keyboard and RS 232/RS 422 interface ports. Internal memory should be sized to permit storage of standard (reference) signatures, part programs, and statistics on board discrepancies. The position system should be capable of indexing .025 inches in 500 milliseconds and complete a joint inspection in 200 milliseconds.

The laser should be a standard YAG laser with 30 watts of power. A secondary He-Ne laser shall be provided for beam-to-joint positioning.

5.0 RESULTS OF INVESTIGATION

During development of the system requirements, it became obvious that laser soldering of leaded components presented a challenge. First was the development of an acceptable method of applying sufficient solder on the joint to permit bonding. The proposed method attempted to imitate and automate a hand-soldering process. This proved awkward and ultimately was discarded for an overplating method. Overplating the pads by depositing three to four times the normal amount of solder showed promise since the process is currently employed to process surface mount boards. However, as Tracor began uncovering additional information, it discovered that while the process works well on surface mount boards, it tends to reduce hole diameter (lead through boards) by as much as 25%. This reduction in hole diameter restricted the percent yield on automated insertion and increased the handwork required to complete component insertion. Another issue affecting the use of overplated pads was the engineering change, product recertification, and configuration control requirements. Since a majority of the board assemblies produced by Tracor are for DoD customers, the introduction of a new process must pass a series of tests and the products recertified. Many of these products were designed, tested, and certified several years ago and such have approached product stability. Efforts to redesign and recertify the boards and products provided a costly alternative to achieving the expected benefits from laser soldering. Thus the idea to overplate the pads was rejected.

In addition to the solder deposition problem, Tracor faced a situation of controlling component movement and beam positioning during laser soldering. Currently boards are brought to the soldering operation in a loose component configuration. With wave soldering the leads pass over a continuous wave and physical component placement is not a problem. With laser soldering, however, component positioning is critical since the beam strikes the top side of a joint or pad. Component misalignment will cause the system to skip. With currently available laser positioning tables, the inertia placed on the components when indexing .025 inches in 500 milliseconds is extremely large and tends to displace the loose components. Indexing the boards at a slower rate would drastically increase throughput.

While a single manufacturer did offer a moving beam delivery system for positioning the laser beam over the stationary work, maintaining component perpendicularity remained a problem.

Variances reported to Tracor engineers by laser solder vendors and actual users raised questions on whether laser soldering was a practical and cost effective alternative to wave soldering. In fielding information from laser solder vendors it was reported that a joint-to-joint cycle time of 700 milliseconds was achievable. When actual users were asked the question, joint-to-joint cycle times of 4 seconds were voiced. This alarming difference of fivefold raised concern over the number of laser solder units required to meet projected production rates.

During Phase I Tracor sampled its four major product lines (FRCT, TRTT, Countermeasures, and Omega) and arrived at an average joint count per board of 600. For the year 1985, Tracor has forecasted for these product lines approximately 57,000 boards, or 34.2 million joints. Similar production projections are forecasted for the next five years. Using an annual rate of 57,000 boards and an optimistic cycle time of 1, 2, or 3 seconds per joint, it can be deduced that as few as two machines or as many as five machines working three shifts/day would be required to support Tracor's production requirements (note that these rates do not consider minor production programs).

The inability to achieve adequate throughput, combined with the need of 3-5 additional laser solder machines, led to a rough cost benefit analysis and briefing to the Tech Mod Steering Committee.

6.0 COST BENEFIT ANALYSIS

The Phase I cost analysis placed projected annual savings at approximately $550,000. This figure was based on 1) estimated touch-up times, 2) projected labor of one operator per laser solder/inspection system, and 3) the assumption that the process would reduce the cost of labor by some percent.

During the Phase II effort, Tracor began tracking labor to the operation. Sampling each major product line (FRCT, TRTT, Omega and Countermeasures) and the labor force from mask, solder, touch-up, and inspect, it was found that Tracor spent an average time of 5.8 seconds per solder joint. Tracor's investigation during the systems requirement activities found that users of laser solder were experiencing approximately 4 seconds per joint. Combining this 4 seconds with a rate of 300 milliseconds per joint to inspect resulted in an improvement of 1.5 seconds per joint over current methods. While direct/indirect labor reductions would result from a more automated process, the absorption of three additional laser solder machines, plus the cost to redesign, retest and recertify, and maintain configuration control (resulting from overplating), could not offset the expected savings. The results of the investigation and cost analysis were presented to Tracor's Steering Committee, which concurred with the findings and favored termination of the project.