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Symbology Research Center LTR SRC-01-001

USAF Aging Landing Gear Life Extension Program Marking Test Report

General Atomics Purchase Order Number H033303
USAF Program Number 39035
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March 29, 2001

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RVSI Acuity CiMatrix

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PREFACE

The marking methods currently approved for use on Department of Defense (DOD) programs/projects were developed to apply human readable markings to larger size structures, mechanical component, and piece parts. While these marking methods have proven to be adequate for this purpose, they generally do not provide the fidelity need to apply machine-readable symbols, and often fail to remain readable after being subjected to overhaul processes. Recognizing these problems, and being faced with the same part traceability issues, the National Aeronautics and Space Administration (NASA) undertook the task of identifying new direct part marking (DPM) techniques designed specifically for the application of 2-D symbols to aerospace materials. During this program, NASA successfully demonstrated that 2-D symbols applied using DPM methods and techniques were safe for use in the aerospace applications if applied correctly. These DPM methods and subsequent methods and techniques identified by RVSI, however, have not undergone testing to ensure that they will remain readable after being subjected to normal aircraft overhaul processes. With this in mind, the United States Air Force (OO-ALC/LILE organization) elected to subject materials marked with 2-D symbols to their normal aircraft landing gear part overhaul conditions (NALGPOC) to determine mark survivability rates.

This report includes: the requirements for the test program (Appendix A), parameters used to apply and read the markings (Appendix B), photographs of the various marking types applied to the USAF test coupons (Appendix C) and, copies of all previous non-proprietary 2-D marking tests reports that the RVSI SRC was able to locate (Appendix D).

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1.0 INTRODUCTION

This test report summarizes the results of the marking application portion of the USAF Aging Landing Gear Life Extension Program. The work was accomplished by RVSI's Symbology Research Center (SRC) in response to General Atomics Purchase Order Number H033303, issued as defined by USAF Program Number M-E-39035-112-10000-6 Rev C.

2.0 PURPOSE

The purpose of the marking project was to apply Data Matrix symbols to selected aircraft materials using permanent Direct Part Marking (DPM) methods. The marked materials (test coupons) were than shipped to Hill AFB where they were subsequently processed through normal landing gear part overhaul conditions (NLGPOC). All of the markings were applied using methods and techniques defined in the following government documents:

- NASA-STD-6002 (P026), Final Draft - Standard for Applying Data Matrix Identification Symbols on Aerospace Parts
- NASA-HDBK-6003 (P027), Final Draft – Application of Data Matrix Identification Symbols to Aerospace Parts Using Direct Part Marking Methods/Techniques

The SRC also provided samples of new marking processes that are currently under development for USAF evaluation. These processes are described in paragraphs 4.9 (investment casting) and 4.10 (plasma spray).

3.0 APPROACH

RVSI engineers applied test markings to practice coupons made of two different material types (4340 – per AMS 6415 9 and AL 7075-T7351 – per AMS 4078) to determine the optimal settings required to apply easily decodable symbols (AIM mark quality grade of B or greater). Finished markings were then applied to test coupons using eight different DPM processes: 1) Dot Peening, 2) LaserShot Peening™, 3) Micro-milling, 4) Laser Bonding, 5) Laser Etching, 6) Laser Engraving, 7) Gas Assisted laser Etch (GALE) and, 8) Laser Induced Surface Improvement (LISI). Marking and reading parameters associated with the above tasks are recorded on data sheets contained in Appendix A. Photographs of the various markings are included in Appendix B.

4.0 MARKING SYSTEM DESCRIPTIONS

4.1 Dot Peen

Dot peening is achieved by striking a carbide or diamond tipped marker stylus against the surface of the material being marked. Symbol size is controlled by the size and tip angle of the stylus, dot spacing, or by altering the number of strikes per data cell. Single strikes are used to create small symbols. Multiple strikes may be used to create larger symbols. An odd number of strikes is recommended to create data cells to ensure that a recess is located in the center of each data cell (e.g., 3x3, 5x5, 7x7, etc.).

Dot peen marking is generally limited to parts exposed to harsh manufacturing, operational, and/or refurbishment conditions. Since many of these conditions change surface properties and/or color, it may be necessary to modify the surface to restore readability. This can be accomplished using a weld cleaner to remove oxides from the surface or by back filling the dot recesses with a removable media of contrasting color, usually dry erase ink or chalk.

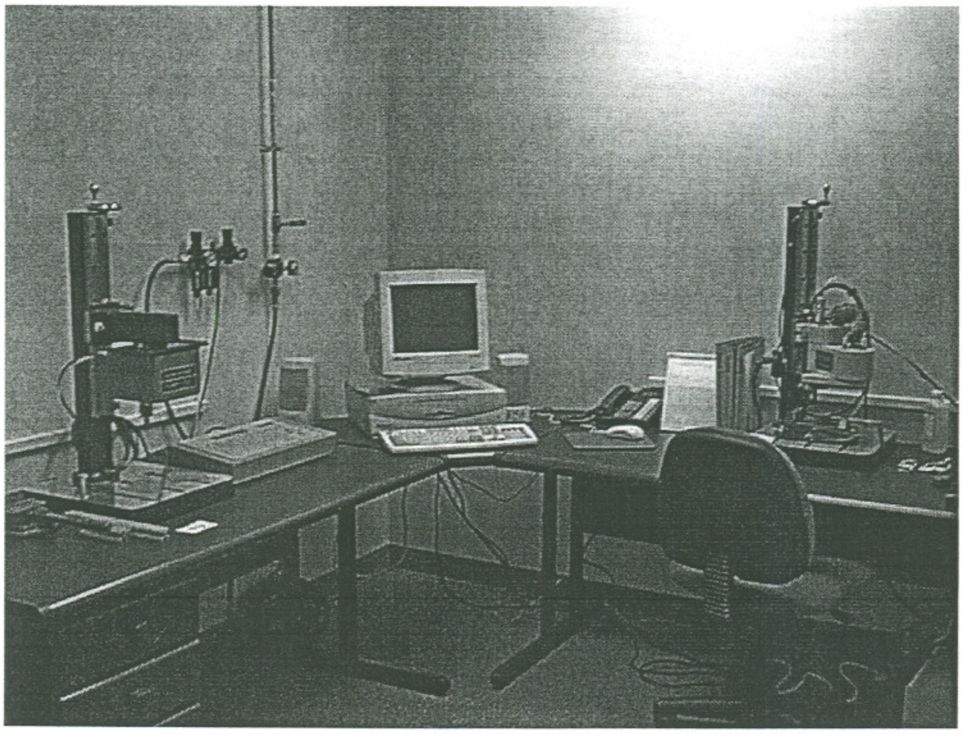

Figure 1 -Typical Dot Peen Station

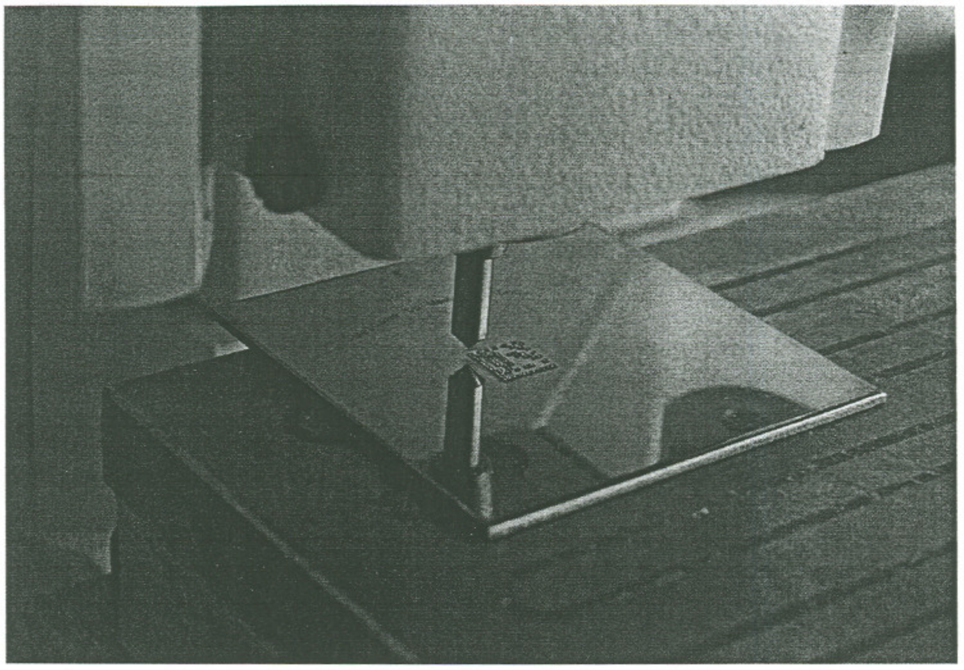

Figure 2 - Close up of Dot Peen Marking Process

4.2 LaserShot Peen

Lasershot peen marking is a marking process for metal components that imprints an identification coding and leaves the surface in residual compressive stress. The technique involves the use of a laser peening system that impresses an image generated in the near field spatial profile of the laser beam onto the metal in the form of a relief pattern. The creation of a compressive stress is highly advantageous for safety critical parts as it leaves the component resistant to fatigue failure and stress corrosion cracking.

In the laser peening process a thin layer of absorptive material is placed over the area to be peened and a thin, approximately 1 mm thick layer of fluid is flowed over the absorption layer. A high intensity laser with fluence of approximately 100 J/cm2 and pulse duration of 15 ns, illuminates and ablates material from the absorption layer, creating an intense pressure pulse initially confined by the water layer. This pressure creates a shock wave that strains the metal surface in a two-dimensional pattern directly correlated to the laser intensity profile at the metal surface. By creating a desired pattern upstream in the light field and imaging this pattern onto the metal surface, the entire desired pattern can be pressure printed with a single laser pulse.

By employing spatial light modulation of the near field beam and subsequent imaging of this pattern onto the metal, a completely new data matrix can be created with each laser pulse. Essentially any two or three-dimensional pattern can be printed including the data matrix standard as well as bar codes and alpha-numerics.

A breakthrough in laser technology employing a Nd:glass laser and a wavefront correction technology called phase conjugation now enables the building of a laser system that can operate a 6 pulses per second with output energy of up to 100J. This represents a fundamental capability of peen marking 6 complete data matrices per second.

Lasershot peen marking can be used on any non-brittle material that undergoes plastic strain upon reaching its stress yield point. It will not work well on materials that fracture such as glass. The process can be combined with an overall shot peening or lasershot peening of the surface to provide excellent protection against fatigue failure and stress corrosion cracking.

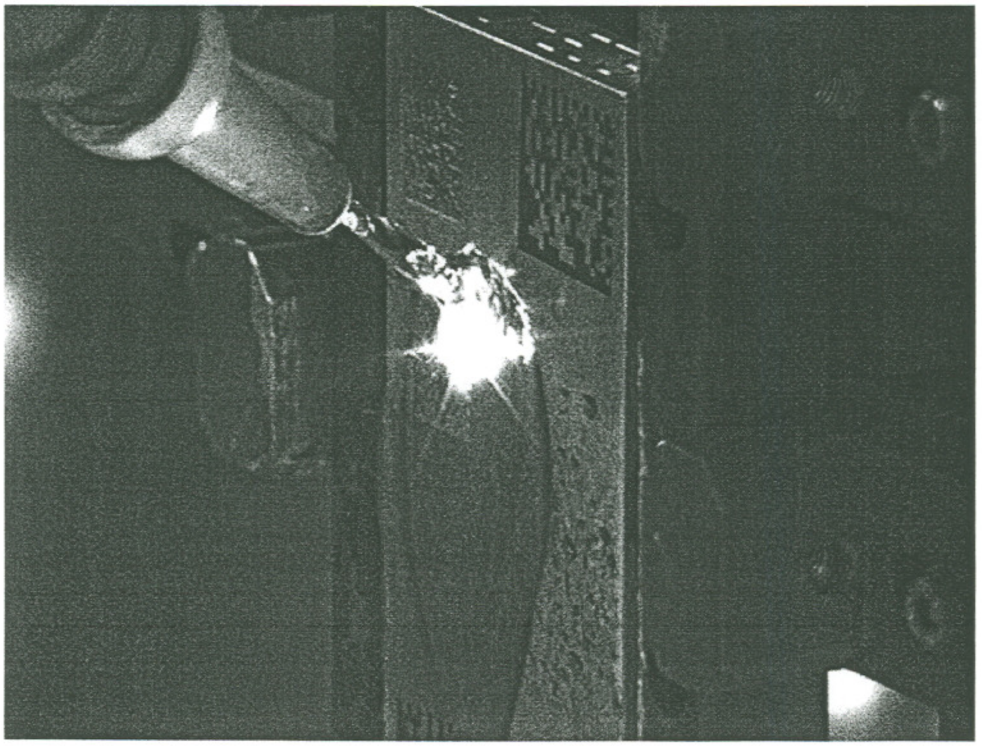

Figure 3 - Close up of Laser Shotpeen Marking Process

4.3 Micro-milling

Micro-milled markings are applied by removing material from the parts surface using a computer-guided carbide tipped cutter or diamond drag. The quality of the marking is controlled by adjusting cutting depth, air pressure, rotation, and dwell time. Marking readability can be improved by backfilling the marking recesses with a material of contrasting color. Engraved markings can be applied to glass, plastic, phenolic, ferrous and non-ferrous metals.

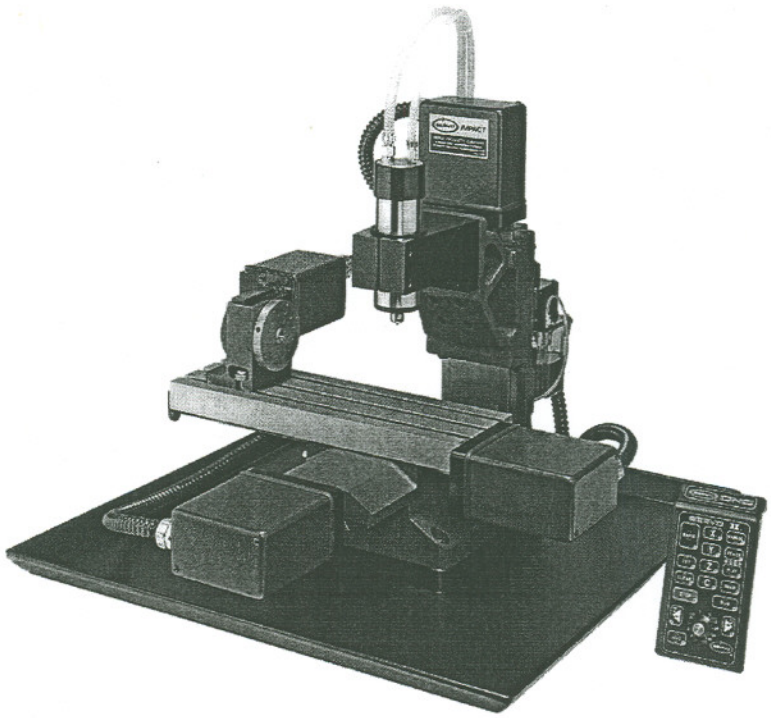

Figure 4 – Typical Micro-Milling Marking Station

4.4 Laser Bonding

Laser bonding is an additive process that involves the bonding of a material to the substrate surface using the heat generated by a Nd:YAG, YVO_4, or CO_2 laser. The materials used in this process are commercially available and generally consist of a glass frit powder or ground metal, oxides mixed with inorganic pigment, and a liquid carrier (usually water). The pigment can be painted or sprayed directly onto the surface to be marked, or transferred via pad printer, screen printer, or coating roller.

Adhesive backed tapes coated with an additive are also used in this process. The process also can also be performed using a CO_2 laser and ink foils for use in less harsh environments.

Laser bonding is accomplished using heat levels that have no noticeable affect on metal or glass substrates and are safe for use in safety critical applications. The markings produced using this technique (dependant upon the material used), are resistant to high heat, are unaffected by salt fog/spray and are extremely durable.

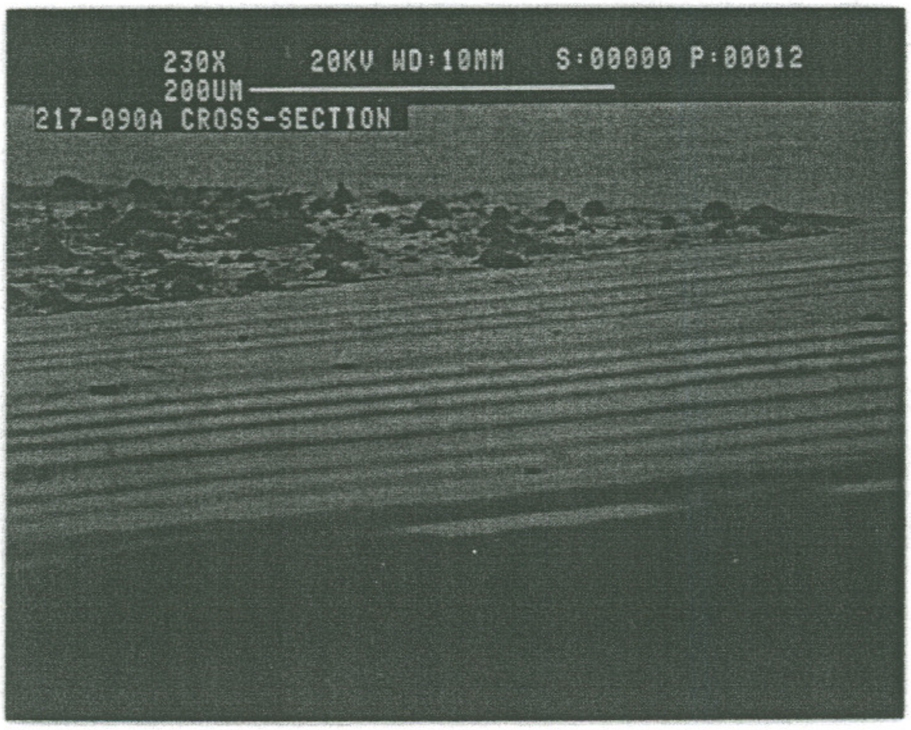

Figure 5 – Magnified view of Laser Bonded Marking

4.5 Laser Etching

Laser etching is similar to laser coloring except that the heat applied to the surface is increased to a level that causes substrate surface melting. The advantage to using this technique on metal over laser coloring is increased marking speed. Excellent results can be routinely obtained at penetration depths of less than 0.001-inch.

This technique, however, should not be used on some metals used in safety critical parts because cracks produced in the molten metal during cooling can propagate into the underlying surface material. These cracks can expand downward if the part is stressed and/or after repeated hot and cold cycles. These conditions can led to part failures.

Laser etched marking can generally be felt when rubbed with a finger and have a corn row (swipe mode) or cratered (dot mode) appearance when viewed under low (10X) magnification. Laser etching is not recommended for parts thinner than 0.050-inches.

Laser etching can be safely used in safety critical applications to mark coatings applied to substrates. The process, known in the industry as *Coat and Mark,* has been successfully demonstrated on materials used to coat aircraft aluminum surfaces and external aircraft engine components subjected to temperatures up to 2000 degrees Fahrenheit.

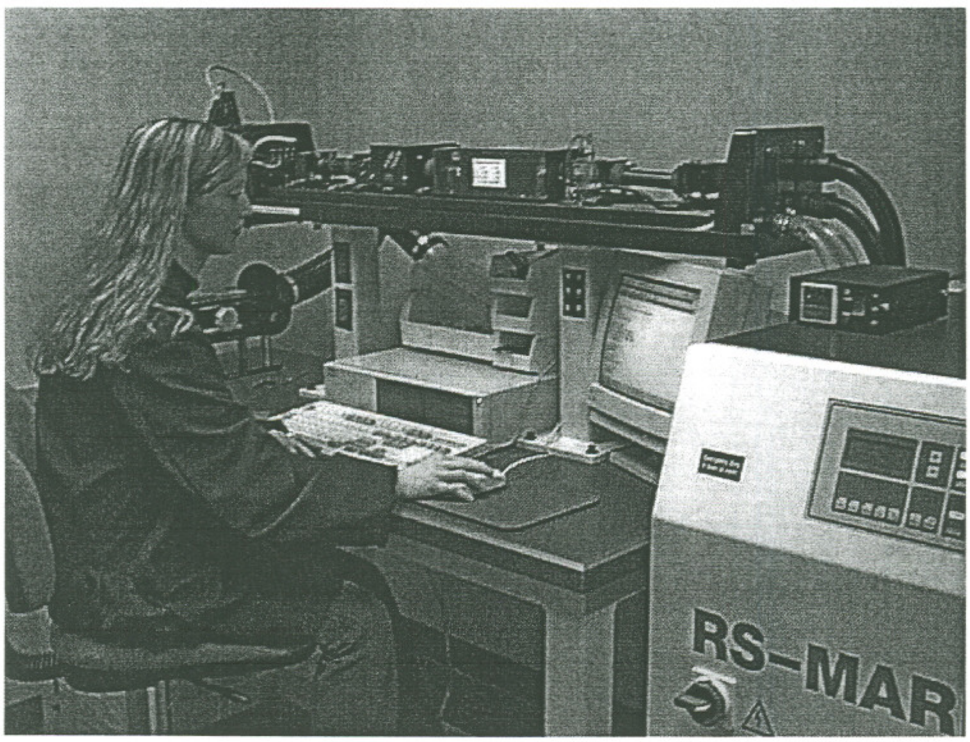

Figure 6 - Typical Nd:YAG Laser Marking Station

4.6 Laser Engraving

Laser engraving involves more heat than laser etching and results in the removal of substrate material through vaporization. This technique produces a deep light marking similar to a deep electro-chemical etch marking. The major advantage of this laser marking technique is speed, because it is the quickest laser marking that can be produced. The high contrast obtained by laser coloring or etching, cannot be obtained by laser engraving because the discolored material is vaporized and ejected during the marking process. Although this method appears to be the most vigorous laser marking technique, it generally produces less damage to the substrate than laser etching. However, because it can produce micro cracking in some materials, it's use in safety critical applications should be studied by a metallurgist prior to use. Like laser etching, direct laser engraving can be easily determined by touch and low power microscope (10X) magnification.

Laser engraving is acceptable for use in safety critical applications when used in conjunction with a C*oat and Remove* process. The *Coat and Remove* process involves the coating of a part with a media of contrasting color that is subsequently removed to expose the underlying material . The marking is as resilient as the surface coating used in the process.

4.7 Gas Assisted Laser Etch (GALE)

Ambient environment laser marking often results in a limited degree of contrast between the engraved mark and the background on which it is placed. This can limit the speed of the mark and the number of different materials that can be marked. The gas-assisted laser etch (GALE) technique can be used to mark an object in the presence of a selected gaseous environment, thus enhancing contrast and increasing readability. The mark is made using low power settings, enabling the mark to be made with minimal laser interaction with the target material. GALE accomplishes this by the use of an assist gas that reacts with the material under the influence of the laser energy to produce a reactant that is a different reflective color from the background. The assist gases might be reducing, oxidizing or even inert, their selection being dependent upon the target material.

A contrasting surface results at the coincident point of the laser, the gas and the material, producing a high contrast, readable mark created in a controlled environment. Tests performed at the University of Tennessee Space Institute have demonstrated that the process should be safe for use in most aerospace marking applications.

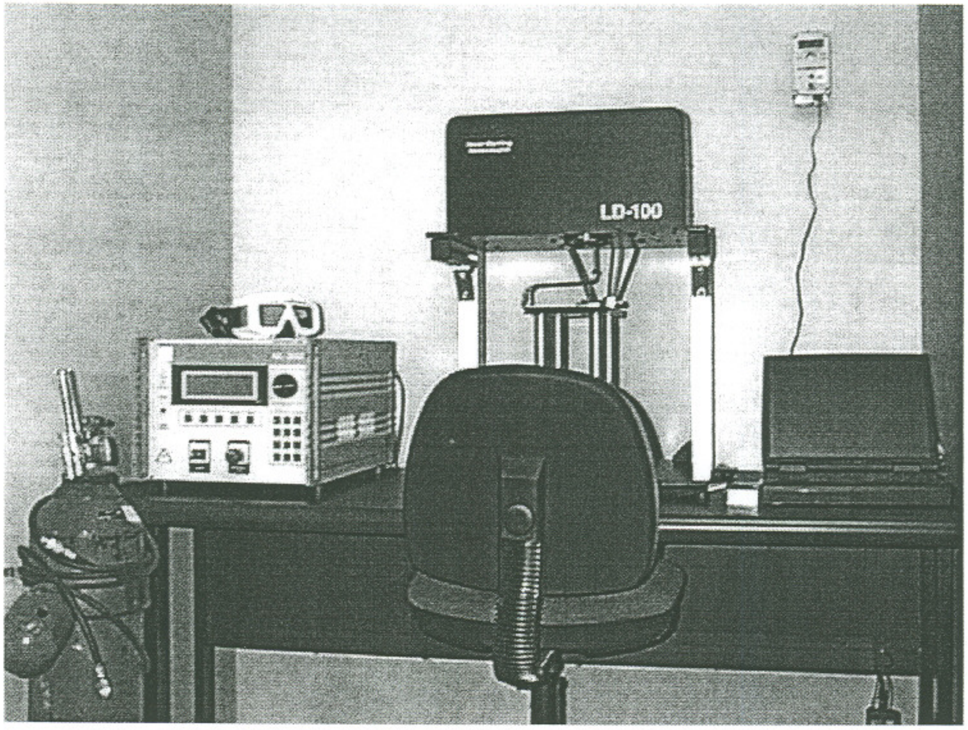

Figure 7 – Typical Gas Assisted Laser Etch Marking Station

4.8 Laser Induced Surface Improvement (LISI)

Laser induced surface improvement (LISI) is similar to laser bonding except that the additive material is melted into the metallic host substrate to form an improved alloy with high corrosion resistance and wear properties. LISI is generally used as a surface coating but can be applied directly to parts to form a representation of a symbol. Where required, a LISI patch can be applied that is subsequently marked using another intrusive or non-intrusive marking method. The process is generally used to mark steel parts that rust when exposed to their normal operating environment.

4.9 Investment Casting

Cast metal marking of the 2-D Data Matrix identification symbols is achieved by printing a pattern of the Data Matrix symbol in physical or 3-dimensional form on a 3-dimensional printer such as the ThermoJet Solid Object Printer by 3-D Systems. These 3-dimensional printing devices produce physical objects by using an ink jet print head that uses a wax based thermoplastic instead of ink, and prints layer upon layer to build up the "ink" thickness into a 3-dimensional object. For the cast metal marking application the 3-dimensional printed pattern of the Data Matrix symbol is incorporated into a coupon made from the wax-based thermoplastic material. Once printed this coupon can be turned into a cast metal equivalent by putting the wax coupon pattern through the investment casting process.

For direct part marking of investment cast parts, these wax coupons would be directly attached to the wax pattern of the part to be marked before being put through the investment casting process. For parts that are fabricated using sand casting the wax coupons containing the Data Matrix symbology would be placed into a recess in the mold pattern before the sand mold is compacted and formed. For parts produced by the molding or forged fabrication processes the wax coupons containing the Data Matrix symbology would be investment cast first to produce a cast metal coupon which would be inserted into a recess in the mold before the end use part is fabricated in the mold.

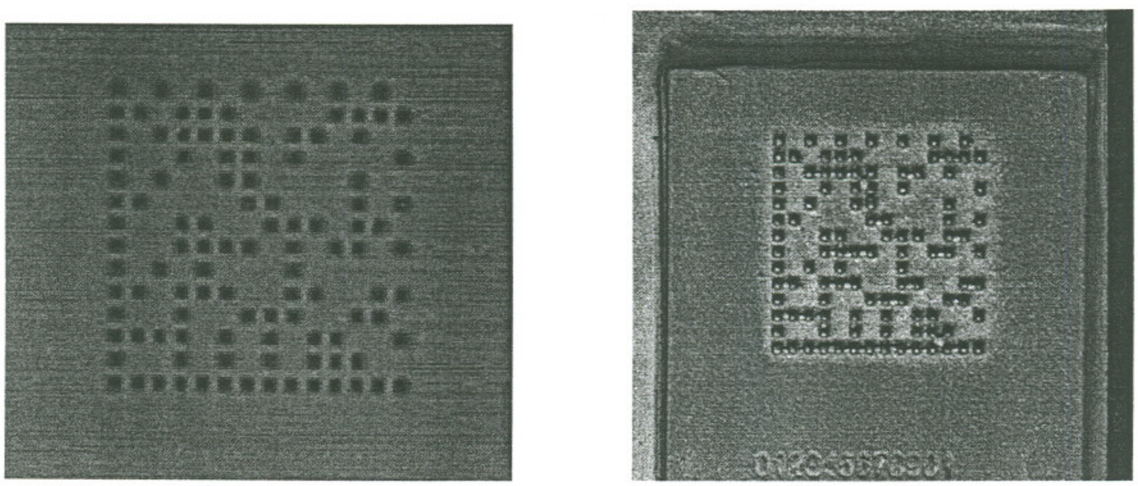

Figure 8 – Wax mold and Resulting Investment Casing

4.10 Sand Casting

To be incorporated in a separate report.

4.11 Plasma Spray

To be incorporated in a separate report.

5.0 Decoding Tests

All of the test markings were evaluated for mark quality and decodability. Mark quality was evaluated using RVSI Verifier software. This software is configured to comply with AIM standards for bar code verification. The AIM standard was designed to evaluate high contrast paper labels. Although contrast is critical with 1D bar codes, contrast levels are not a critical measurement for Data Matrix symbols since RVSI readers are equally capable of reading Data Matrix symbols with contrasts as low as 20% (D grade by AIM standard). All marks applied to the USAF coupons received an "A" grade with the exception of a few applied to the darker heat-treated steel coupons. The lowest grade in this category was a "C". The decoding tests were conducted using both fixed station and handheld readers under a variety of different lighting conditions, i.e., total darkness to 2,000 candlepower. Handheld tests were conducted with the reader positioned at 90 degrees ± 10 degrees to simulate conditions typically seen in field use.

6.0 Summary

The marking portion of the USAF Aging Landing Gear Life Extension Program was successfully completed on March 28, 2001. All of the markings produced were of high quality and decoded without difficulty using RVSI fixed station and MXi hand-held readers. The marked coupons were shipped to Hill AFB for testing on March 30, 2001. The SRC is continually developing new marking processes for industry and forward samples of new marking processes to the USAF as developed.

APPENDIX A

PROGRAM REQUIREMENTS

APPENDIX C

MARKING PHOTOGRAPHS

APPENDIX D

PREVIOUS TEST DATA

Appendix D

Item No.	Source	Document Number	Date	Document Title
1	**Pratt & Whitney**	**Lab Test Report 23211**	December 24, 1980	**Metallurgical Evaluation of Laser Marking on PWA 1422 1st Stage Turbine Blades.**
2	**Rockwell International**	**NASA Special Task Assignment 168-R1**	May 11, 1987	**Vericode Machine-Readable Symbology Technical Evaluation**
3	**Rockwell International**	**Letter 92MA0046**	January 15, 1992	**Vericode Automatic Identification System Evaluation Report**
4	**Rockwell International**	**Summary Report SSD92-M-0019**	February 20, 1992	**Vericode Automatic Identification System Evaluation Summary Report**
5	**Rockwell International**	**Lab Test Report 240-1234**	April 1992	**Analysis of Vericode Marked Tile**
6	**Rockwell International**	**Lab Test Report PTN 027937**	September 17, 1992	**Evaluation of Laser Marked Vericodes on Turbine Blades**
7	**Rockwell International**	**Lab Test Report PTN 027940**	September 24, 1992	**Evaluation of Laser Marked Ti-6Al-4V**
8	**Rockwell International**	**Letter 284-202-92-079**	November 16, 1992	**Preliminary Evaluation of Laser Marked Mar-M-246 and Ti-6Al-4V**
9	**NASA MSFC**	**Program Report SSD92-M-0024**	April 23, 1993	**Vericode Symbol Automatic Identification System Marking Test Program**
10	**NASA MSFC**	**Program Report SSD93-M-0029**	May 4, 1993	**Vericode Symbol Automatic Identification System Marking Test Program**
11	**Rockwell International**	**Lab Test Report 6158-2470**	August 1993	**Evaluation of Vericode Laser Marked Materials**
12	**Ohio University**	**Lab Test Report 93-SL161**	September 1993	**Data Matrix and PDF417 Data Integrity Test**
13	**Rockwell International**	**Preliminary Screening Tests NAS8-40000**	December 1993	**High Cycle Fatigue Testing of Selected Materials Marked with Vericode Symbols**
14	**Rockwell International**	**Letter 93MA4416**	January 6, 1994	**Integration of Automated Part Identification (API) into the Configuration Verification and Accounting System**
15	**Pratt & Whitney**	**Government Engine Business Letter**	March 7, 1995	**Compressed Symbology Marking for SSME Parts**
16	**Rockwell**	**Letter 284-200-95-155**	July 19, 1995	**Results of Vericode Marking Test Program**

	International			

Appendix D Continued

Item No.	Source	Document Number	Date	Document Title
17	University of Tennessee Space Institute	Letter SRC-97-163	January 5, 1998	**Laser Settings**
18	Ohio University	Executive Summary 99-28	January 12, 1998	**Data Matrix And PDF 417 Data Integrity Test**
19	University of Tennessee Space Institute	CiMatrix Clearcoat Testing Report	March 31, 1998	Wear and Corrosion Testing of Coated Laser Marks on Anodized Aluminum
20	United States Coast Guard	Report DTCG38-97-C-300004	June 26, 1998	Aircraft Flight Critical Part Verification System Final Report
21	Cerdec	Email and Photos	December 19, 2000	Height of LMM-6000 Laser Marks
22	Cerdec	LLM Test Results	January 3, 2001	Physical Testing of LMM-6000 Laser Marks
23	Lawrence Livermore National Laboratory	Email and Powerpoint Slides	January 8, 2001	Test Data for Laser Peening on Various Materials
24	RVSI Acuity CiMatrix	Email/Letter	**January 31, 2001**	Photo Process, Electro-Chemical Marking Evaluation.