**National Aeronautics and
Space Administration**

APPLYING DATA MATRIX IDENTIFICATION SYMBOLS ON AEROSPACE PARTS

NASA TECHNICAL STANDARD

FORWARD

This Standard and its related Handbook, NASA-HDBK-6003A, *Application of Data Matrix Identification Symbols to Aerospace Parts Using Direct Part Marking Methods/Techniques*, were developed to provide NASA and its contractors with instructions to safely apply Data Matrix identification symbols to aerospace parts using these new DPM methods and techniques. Both the Standard and the Handbook were created by representatives from major automatic identification and data capture (AI/DC) manufacturers, Government and aerospace user groups under a collaborative agreement with NASA and have been approved for use by NASA Headquarters and all field installations and is intended to provide a common framework for consistent practices across NASA programs.

Requests for information, corrections or additions to this handbook should be directed to Materials, Processes, and Manufacturing Department, ED30, MSFC, AL, 35812. Requests for general information concerning standards should be sent to the NASA Technical Standards Program Office, ED41, MSFC, AL 35812 (telephone 256-544-2448). This and other NASA standards/handbooks may be viewed and downloaded, free-of-charge, from the NASA Standards Homepage: http://standards.nasa.gov.

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BACKGROUND

Recognizing that manual data collection and keyed data entry were inefficient and error-prone, NASA adopted bar code in the mid 1980s to upgrade its operations. It soon became apparent that collecting the identity of the part from a symbol marked directly on it would be optimal. Bar codes were determined to not be suitable for direct part marking (DPM). NASA established a team to work with industry to develop and test machine-readable two-dimensional (2-D) symbols designed to be applied to non-paper substrates. This 5-year effort resulted in selecting the Data Matrix symbol for use in NASA applications and provided proof that 2-D symbols are reliable and can be applied to most aerospace materials without impacting performance. NASA findings spurred additional testing by the Department of Defense (DoD) and private industry that resulted in selecting the Data Matrix symbol for parts marking by the Automated Identification Manufacturers (AIM). Additional part marking standards quickly followed as the automotive, electronics, pharmaceutical, and aircraft industries adopted the symbol.

These industries, including NASA, have relied heavily on the use of mold, cast, or forge; engraving; electrical arc pencil; electrical-chemical marking; embossing; hot stamp; rubber ink stamp; stencil and silk screen; vibration-etch; and add-on tags for part identification marking. These marking methods, originally designed to apply human-readable markings, do not provide the fidelity required to successfully apply micro-size (1/32-inch [0.79 mm] to 15/64-inch [5.95 mm] square), high-density machine-readable symbols. Their manual operations also added to the large number of data transposition errors associated with paper-based manufacturing systems.

Understanding these weaknesses, the parts identification industry began to refine existing marking methods so they could be utilized to apply 2-D symbols. The manual metal stamp, vibro-etch, and embossing technique methods were replaced by dot peen machines. Automated micro-profilers were designed to replace the manual cutting wheel used to produce paint stencils. Photo stencils and thermal printing materials were developed to replace the direct impact electro-chemical marking stencil materials. Ink jet and adhesive dispensing machines were built to replace rubber stamps. Laser marking systems were designed to replace the electric-arc etch and hot stamp processes. These new marking processes have been incorporated into this standard.

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APPLYING DATA MATRIX IDENTIFICATION SYMBOLS
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1.   SCOPE

    1.1   Scope. This standard establishes uniform requirements for applying Data Matrix identification symbols to parts used on NASA programs/projects using direct part marking (DPM) methods and techniques. Overall program/project requirements related to the use of the Data Matrix symbol include: symbol criteria, marking method selection, marking surface preparation, marking location, protective coatings, and reading standards. This document addresses the marking of human readable characters or temporary part identification markings (bands, labels, or tags). On new programs, human readable characters can be applied using the same marking methods defined in this standard. Data Matrix symbols can be added to parts used on existing programs, provided there is adequate area to accommodate the mark and the structural integrity of the part is not compromised.

    1.2   Purpose. This standard is intended to provide general requirements for applying Data Matrix identification symbols safely onto products using permanent direct part marking (DPM) methods and techniques. The standard addresses symbol structure only as it relates to marking and reading limitations. Technical specifications related to the Data Matrix symbol are found in AIM International, Inc. technical specification titled "International Symbology Specification – Data Matrix. Technical information related to how to apply the markings is addressed in NASA-HDBK-6003A, *Application of Data Matrix Identification Symbols to Aerospace Parts Using Direct Part Marking Methods/Techniques.*

    1.3   Applicability. This standard recommends engineering practices for NASA programs and projects. It may be cited in contracts and program documents as a technical requirement or as a reference for guidance. Determining the suitability of this handbook and its provisions is the responsibility of program/project management and the performing organization. Individual provisions of this standard may be tailored (i.e., modified or deleted) by contract or program specifications to meet specific program/project needs and constraints. Human readable markings applied to NASA aircraft maintained under FAA certificate (e.g., Part 121, Part 135) shall comply with the requirements of Title 14 of the Code of Federal Regulations.

    1.4   Environmental Stewardship. Environmental, health and safety impacts in processes and materials should be considered when employing identification marking methods and techniques. Alternative, "environmentally friendly", materials, which contain low/no volatile organic compounds (VOCs), should be considered when determining the appropriate method/technique for each marking application. Many types of ink contain VOCs, such as methyl ethyl ketone, xylene, and toluene, which are principal components in atmospheric reactions that form ozone and other photochemical oxidants. Exposures to VOC containing materials have health impacts, which include eye and respiratory irritation, headache, dizziness, memory impairment, neurotoxicity, cancer.

2.   APPLICABLE DOCUMENTS

    2.1   General. The applicable documents cited in this standard are listed in this section for reference only. The specified technical requirements listed in the body of this document must be met whether or not the source document is listed in this section.

2.2 <u>Government documents</u>.

2.2.1 <u>Specifications, standards and handbooks</u>. The following specifications, standards, and handbooks form a part of this document to the extent specified herein. Unless otherwise specified, the issuance in effect on date of invitation for bids or request for proposals shall apply.

DEPARTMENT OF DEFENSE
MIL-STD-10A – Surface Roughness Waviness & Lay

MIL-STD-130 – Identification Marking of U.S. Military Property available from HQ AFLC, ATTN: MMTIB, Wright-Patterson Air Force Base, OH 45433

MIL-A-8625 – Anodic Coatings For Aluminum And Aluminum Alloys

MIL-M-13231 – Marking of Electronic Items

FEDERAL STANDARDS
FED-STD-182 – Continuous Identification Marking of Nickel and Nickel Base Alloys

FED-STD-183 – Continuous Identification Marking of Iron and Steel Products

FED-STD-184 – Identification Marking of Aluminum, Magnesium, and Titanium

FED-STD-185 – Identification Marking of Copper and Copper Base Alloy Mill Products

FED-STD-595 – Colors Used In Government Procurement (Fan Deck)

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
None identified.

2.2.2 <u>Other Government documents, drawings, and publications</u>.

Title 14 of the Code of Federal Regulations

2.2.3. <u>Non-Government publications</u>. The following documents form a part of this document to the extent specified herein. Unless otherwise specified, the issuance in effect on the date of invitation for bids or request for proposal shall apply.

AIAG B-4, Component Marking Standard (Data Matrix) – Pending

AIM [USA] Uniform Symbology Specification for Data Matrix

American National Standard X3.182 Bar Code Print Quality Guidelines – available from the American National Standards Institute (ANSI), 11 West 42nd Street, New York, NY 10036. Telephone (212) 642-4900

ASM Handbook, Surface Engineering, Volume 5. Available from ASM International, Materials Park, OH 44073-0002.

ASTM B-117-97, Standard Practice for Operating Salt Spray (Fog) Apparatus

ASTM G120, Standard Practice for determination of Soluble Residual Contamination in Materials and Components by Soxhlet Extraction

ASTM G-131, Standard Practice for Cleaning of Materials and Components by Ultrasonic Techniques

ASTM G-144, Standard Test Method for Determination of Residual Contamination of Materials and Components by Total Carbon Analysis Using a High temperature Combustion Analyzer

ASTM D-522-93, Standard Test Methods for Mandrel Bend Test of Attached Organic Coatings

ASTM D-673-93, Standard Test Method for Mar Resistance of Plastics

ASTM D-870-92, Standard Practice for Testing Water Resistance of Coatings Using Water Immersion

ASTM D-1003-95, Standard Test Method for Haze and Luminous Transmittance of Transparent Plastics Transparency

ASTM D-1308 (with addition of sulfuric acid testing), Standard Test Method for Effect of Household Chemicals on Clear and Pigmented Organic Finishes

ASTM 2247-94, Standard Practice for Testing Water Resistance of Coatings in 100% Relative Humidity

ASTM D-2485-91, Standard Test Methods for Evaluating Coatings For High Temperature Service

ASTM D-3359-95, Standard Test Methods for Measuring Adhesion by Tape Test

ASTM D-3363-92, Standard Test Method for Film Hardness by Pencil Test

ASTM D-3794-94, Standard Guide for Testing Coil Coatings

ASTM D-4060-95, Standard Test Method for Abrasion Resistance of Organic Coatings by the Taber Abraser

ASTM G26-95, Standard Practice for Operating Light-Exposure Apparatus (Xenon-Arc Type) With and Without Water for Exposure of Nonmetallic Materials

ASTM G53-96, Standard Practice for Operating Light- and Water-Exposure Apparatus (Fluorescent UV-Condensation Type) for Exposure of Nonmetallic Materials

ASTM E96-95, Standard Test Methods for E96-95 Water Vapor Transmission of Materials

ASTM D2794-93, Standard Test Method for Resistance of Organic Coatings to the Effects of Rapid Deformation (Impact)

ATA Spec-2000, Chapter 9, Bar Coding

EIA-624, Product Packaging Marking

EIA-706, Component Marking Standard (Data Matrix)

EIA-802, Product Marking Standard

EIA SP-3497, Component Product Marking Standard (Data Matrix)

ISO 15415, Two-dimensional symbol print quality – Pending

ISO 16022, Information Technology International Symbology Specification Data Matrix

SEMI T2-95, Specification for Marking of Wafers with Two-Dimensional Matrix Code Symbol

SEMI T7-0997, Specification for the Back Surface of Double-Sided Polished Wafers with a Two-Dimensional Matrix Code Symbol

SEMI T8-0698, Specification for Marking of Glass Flat Panel Display Substrates with A Two-Dimensional Matrix Code Symbol

SEMI T9-0999, Specification for Marking Metal Lead-Frame Strips With a Two-Dimensional Matrix Code Symbols

SEMI Draft Document #2999, Specification for the Assessment of 2D Data Matrix Direct Mark Quality

Uniform Code Council (UCC) Standards. To apply for UCC Manufacturer Identification (Company Prefix) Codes contact Uniform Code Council, 8163 Old Yankee Road, Suite J, Dayton, OH 45458. Telephone (513) 435-3870. Telefax: (513) 435-4749

Uniform Symbology Specification for Data Matrix available from AIM USA, 634 Alpha Drive, Pittsburgh, PA 15238-2802. Telephone (412) 963-8588

UPS S28-1, Identification/Codification Standards (Data Matrix and PDF417) – Pending

2.3 Order of precedence. Where this document is adopted or imposed by contract on a program or project, the technical guidelines of this document take precedence, in case of conflict, over the technical guidelines cited in other referenced documents.

3.   DEFINITIONS AND ACRONYMS

   3.1   Definitions used in this standard

         ASCII.   American Standard Code for Information Interchange. The code is used in the transmission of data. It consists of eight data-bits used to code each alphanumeric character and other symbols.

         Bar Code. A patterned series of vertical bars of varying widths used by a computerized scanner for inventory, pricing, etc.

         Binary Value. A mark on the substrate surface indicates the binary of one. The absence of a mark or a smooth surface surrounding a cell center point, indicates the binary value of zero.

         Bit (Binary Digit) – The basic unit of information in a binary numbering system. 1's and 0's are used in a binary system.

         Centerline, of a row or column – The line positioned parallel to, and spaced equally between, the boundary lines of the row or column

         Character (Data character) – A letter, digit or other member of the ASCII character set.

         Character Set – that character available for encodation in a particular automated identification technology.

         Contrast – This can be thought of as the grayscale difference between two areas of color.

         Data Element – The smallest named item of information that can convey data, analogous of a field in a data record or a word in a sentence.

         Data Element Separator – The special character used to separate data elements ion a data format.

         Data Matrix Symbol – A two-dimensional array of square or round cells arranged in contiguous rows and columns. In certain ECC200 symbols, data regions can be separated by alignment patterns. The data region is surrounded by a finder pattern (AIM – Data Matrix).

         Density (Matrix Density) – The number of rows and columns in a scanned matrix symbol.

         Depth of Etch – The distance from the surface of the substrate to the bottom of the recess created by an etching process.

         Direct Part Marking - Markings applied direct to a parts surface using   intrusive or non-intrusive identification techniques.

         Dot – A localized region with a reflectance which differs from that of the surrounding surface.

Edge – This is seen as a dramatic change in pixel brightness values between regions. It is the point(s) that has the greatest amount of contrast difference (change in intensity values) between pixels.

Electrolyte – The solution formed by water and a selected salt(s) and used as the conductor between an object and electrode in an electro-chemical marking process. Selected electrolytes also have the ability to "color" the mark due to the chemical reaction that takes place between the metal and the electrolyte.

Error Checking (ECC) And Correction – Mathematical techniques used to identify symbol damage and reconstruct the original information, based upon the remaining data in a damaged or poorly printed code. Reed Solomon and convolution are two such techniques.

Field of View – The maximum area that can be viewed through the camera lens or viewed on the monitor.

Finder pattern, of a data matrix code symbol – A perimeter to the data region. Two adjacent sides contain dots in every cell: these are used primarily to define physical size, orientation and symbol distortion. The two opposite sides are made up of cells containing dots in alternate cells (AIM – Data Matrix).

Grayscale – The assignment of a digital value to a degree of light intensity. The shades of gray are used by the computer to reconstruct an image. A common scale is 256 shades of gray, with 0 being black and 255 being white.

Hardness – A measure of the resistance of a material to surface indentation or abrasion; may be thought of as a function of the stress required to produce some specified type of surface deformation. There is no absolute scale for hardness; therefore, to express hardness quantitatively, each type of test has its own scale of arbitrarily defined hardness. Indentation hardness can be measured by Brinell, Rockwell, Vickers, Knoop, and Scleroscope hardness tests.

Human-Readable Identification – The letters, digits or other characters associated with specific symbol characters that are incorporated into linear bar code or two-dimensional symbols.

Intensity – Intensity is the average of the sum total of grayscale value.

Intrusive Marking – Any device designed to alter a material surface to form a human or machine readable symbol. This marking category includes, but is not limited to, devices that abrade, burn, corrode, cut, deform, dissolve, etch, melt, oxidize, or vaporize a material surface.

License tag number – The information contained with the symbol character set to uniquely identify the component. As a minimum the information shall contain the manufacturers CAGE code followed by an asterisk (ASCII separator) and trace code (lot, member or serial number).

Manufacturer – Producer or fabricator of component or the supplier in a transaction if the supplier is the warrantor of the component.

Mark – Refers to a Data Matrix symbol that has been applied to a material surface using a permanent marking method.

Matrix – A set of numbers, terms, or things arranged in rows and columns.

Matrix Density – The number of rows and columns in a matrix.

Non-intrusive Marking – A method of forming markings by adding material to a surface. Non-intrusive marking methods include ink jet, laser bonding, liquid metal jet, silk screen, stencil and thin film deposition.

Part Identification Data – Markings used to relate parts to their design, manufacturing, test, and operational histories.

Permanent Marking – Intrusive or non-intrusive markings designed to remain legible beyond the normal service life of an item.

Photo-Stencil – A silk-screen type fabric coated with a photo-resist compound which can be fixed by UV radiation and easily washed from the fabric where unexposed. The patterns opened in the fabric are the images to be marked (stenciled, etched, or colored) on the substrate.

Pixels – Picture elements. In a camera array, pixels are photoelectric elements capable of converting light into an electrical charge.

Quiet Zone – Areas of high reflectance (spaces) surrounding the machine-readable symbol. Quiet zone requirements may be found in application and symbology specifications. Sometimes called "Clear Area" or "Margin".

Reader – Another name for a CCD or CMOS camera configured to read symbols.

Resolution – The measure of how small a feature the camera can distinguish in its field of view. Camera resolution is determined in its field of view. The number of pixels within the CCD array determines camera resolution. The more pixels used to capture the image, the higher the resolution or quality of the image. Since the number of pixels is fixed, the smaller the field of view, the higher the image resolution will be. For example, a 1-inch (25.4 mm) field of view photographed by a 640 x 480 camera will have a resolution of .0015-inch (0.04 mm) per pixel; a ½-inch (12.7 mm) field of view would yield a resolution of .00078-inch (0.02 mm) per pixel.

Structure – The order of data elements in a message.

Substrate – The material (paper, plastic, metal, etc.) upon which a symbol is marked.

Supplier – The trading partner in a transaction that provides the component (e.g., manufacturer, distributor, reseller, etc.).

Symbology – A machine-readable pattern comprised of a quiet zone, finder pattern, symbol characters (which include special functions and error detection and/or correction characters) required by a particular Symbology.

Temporary Identification – Markings designed to be removed or separated from items before they reach the end of their life cycle.

Thermal Stencil – Similar to the photo-stencil. In this case, the fabric is coated with a compound, which can be opened by a thermal printer to form the desired images.

Traceability – For purposes of this document, traceability is defined as the ability to relate historical documentation to parts using part identification numbers.

3.2 Acronyms used in this standard.

AIM – Automatic Identification Manufacturers

ANSI - The American National Standards Institute. A non-government organization responsible for the coordination of voluntary national (United States) standards. ANSI, 11 West 42nd Street, New York, NY 10036, Telephone: 212.642.4900, Telefax: 212.302.1286

ASTM. - American Society for Testing and Materials

ATA – Aircraft Transportation Association

CAGE Code– Commercial and Government Entity Code

CCD – Charged Coupled Device

CO_2 – Type of laser using carbon dioxide gas as the lasing medium

CMOS – Complementary Metal Oxide Semiconductor

DPM – Direct Part Marking

DOD – Department of Defense

ECC – Error Correction Codes or Error Check and Correction: the Data Matrix code can be printed in 15 error correction levels

GALE – Gas Assisted Laser Etch

ISO – International Standards Organization

KHz – Kilohertz (1000 cycles of oscillation per second)

LASER – Light Amplification by Stimulated Emission of Radiation

LENS – Laser Engineered Net Shaping

LISI – Laser Induced Surface Improvement

LIVD – Laser Induced Vapor Deposition

LMJ – Liquid Metal Jet

NASA - National Aeronautics and Space Administration

Nd:YVO$_4$ – Type of laser using a *Neodymium-doped yttrium vanadate* crystal as the lasing medium

Nd:YAG – Type of laser using a *Neodymium Yttrium Aluminum Garnet* crystal as the lasing medium

NSCM – NATO Supply Code for Manufacturers

WAD – Work Authorization Document

4. GENERAL REQUIREMENTS

4.1 2-D Symbol. The Data Matrix symbol is preferred for direct part identification marking on NASA programs/projects unless otherwise directed by contract. The symbols shall be applied in addition, and in close proximity to, the human readable identification (HRI) markings currently used. On new programs/projects the HRI and symbol marking shall be applied simultaneously and by the same method whenever practical. The Data Matrix symbol is a two-dimensional (2-D) matrix symbology approved by the Automated Identification Manufacturers (AIM) for direct part marking. There are two symbol types: ECC 000 – 140 with several available levels of convolutional error checking and correction (ECC) and ECC 200 which uses Reed-Solomon error correction. For new NASA applications, ECC 200 is required. ECC 000 – 140 should only be used in closed applications where a single party controls both the production and reading of the symbols and is responsible for overall system performance. The characteristics of Data Matrix symbol are defined within the Uniform Symbology Specification for Data Matrix.

When process parameters of symbol size, height or depth must be expressed in linear terms on drawings and other documents, metric equivalents will be included. English units will be used as the "Primary" expression and Metric units will be the "Secondary" expression, shown in parentheses beside the English units.

Data Matrix symbols that are applied to the substrate of a part and subsequently covered with paint, foam, and other protective coatings shall be applied by the same methods identified in this Standard and its related Handbook, NASA-HDBK-6003A, *Application of Data Matrix Identification Symbols to Aerospace Parts Using Direct Part Marking Methods/Techniques*. The imaging of subsurface identification symbols will rely primarily on the ability of a detection device to sense and image or otherwise identify the hidden symbol. Intrusive methods of marking will normally benefit detection devices that sense differences in surface regularity. Non-intrusive or additive methods will normally benefit detection devices that sense substances that exhibit a different characteristic from that of the substrate.

Elemental taggant technology, used in combination with an X-ray fluorescence detection system, is a useful method for identifying and authenticating a part. X-ray fluorescence may be used for detecting elements from the Periodic Table in known concentrations to represent subsurface identification characters. It is recommended that the resulting spectral data output be expressed in the approved Data Matrix format for decoding. The selected elements may be applied as constituents of the Data Matrix symbol marking method or as a standalone identifier. The spectral data output of standalone selected elements, the constituent substances in a

symbol mark, the substrate itself or any combination of these constitute valid part identification only if these conventions are accepted by Engineering.

4.2 2-D Symbol Content. The full part identification data to be encoded into the 2-D symbol shall consist of a part number (PN) that is typically 15 to 21 characters, preceded by the Commercial and Government Entity (CAGE) Code or NATO Supply Code for Manufacturers (NSCM) and followed by a unique serial or lot number, separated by an asterisk (ASCII separator for machine readable identification symbols) or dash (used for HRI). In instances where space is prohibitive, the PN can be excluded from the data content and an abbreviated traceability number used. The traceability number or unique part identification number shall consist of the users CAGE Code or NSCM and unique seven-digit lot number or serial number, separated by an asterisk in the machine readable symbol or dash in the HRI. These data encoding and marking options provide program managers with the ability to use a more damage-resistant symbol (larger data cells) over a greater range of part sizes. Data Matrix symbols that are subsequently covered with paint, foam or other protective coatings shall have the same symbol content requirements as symbols that remain visible throughout their life cycles. Figure 1 illustrates NASA's preferred data content formats.

XXXXX-XXXXXXXXXXXXXXXXXXXXX-XXXXXXX

CAGE/   Part Number   Serial Number
NSCM

XXXXX*XXXXXXX

CAGE/   Serial Number
NSCM

Data format to be used in areas providing sufficient marking area

Data format to be used where marking area is insufficient to place a symbol containing complete data content.
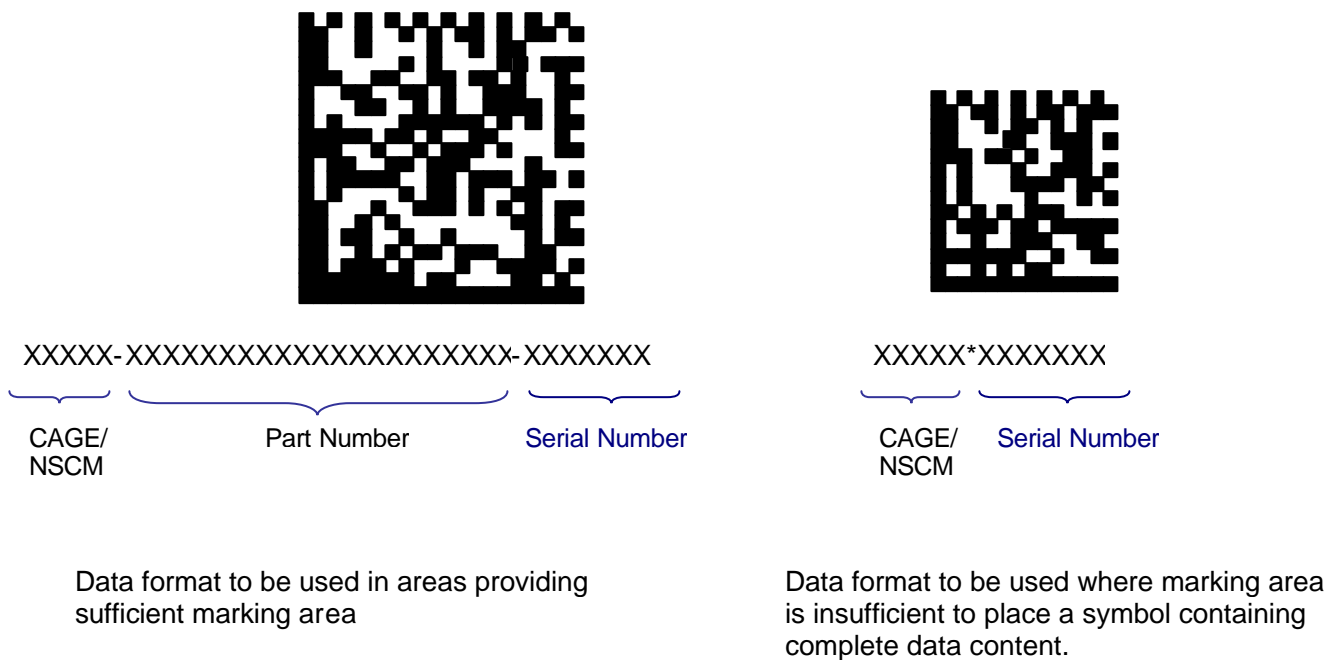
FIGURE 1. Preferred 2-D Symbol Data Content Format

4.3   2-D Symbol Shape. The Data Matrix symbol can be created in square and rectangular formats, the square format being preferred (see Figure 2). However, for some linear shaped parts, such as pipes, lines, narrow part edges, etc., it may be more desirable to use a rectangular shape symbol. The intent is to use a symbol shape providing the largest size data cells.

Preferred symbol shape for narrow marking areas

14X14 Matrix Containing
13 Characters of Data

8X32 Matrix Containing
13 Characters of Data
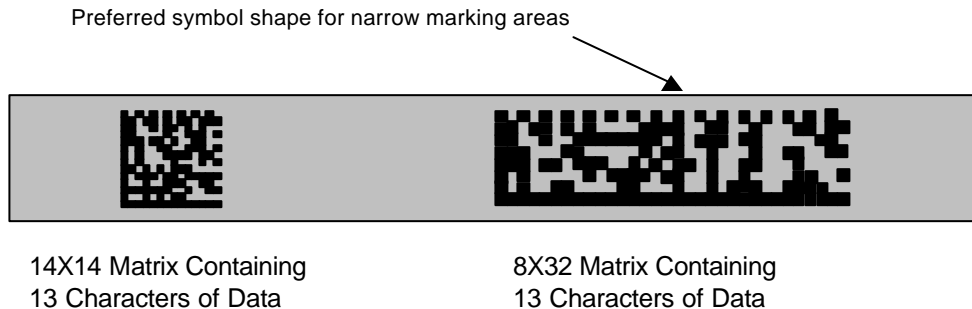
FIGURE 2.   Matrix Symbol Shapes Applied to Elongated Part

The preferred angle between rows and columns is 90% +/- 7 degrees.

4.4   2-D Symbol Size. Data Matrix symbols can be produced in sizes ranging between 4 microns (0.0001016 mm) square to two feet (609.6 mm) square, the limiter being the capability and fidelity of the marker. Symbol size is not an issue using fixed station readers that are configured to accept different size lens or with hand-held readers configured with variable or multiple lenses. Hand-held readers configured with fixed lenses to reduce cost and complexity, are generally limited to reading symbols within specific size ranges, i.e., read small symbols, large symbols, or some compromise zone in between. In general, fixed lens hand-held readers are used in applications where symbol size is fixed and variable or multiple lens readers used in applications requiring the use of different size 2-D symbols and/or bar codes. Regardless of lens type, hand-held readers are generally limited to reading symbols containing individual data cells that measure 0.0075-inches (0.12 mm) across or larger. The overall symbol size shall be less than 1-inch (25.4 mm) (outside dimension of the longest side).

4.5   Part Identification Conflicts. Conflicts between the HRI and the Data Matrix symbol markings must be brought to the attention of quality assurance immediately, and an evaluation conducted. Conflicts shall be resolved and documented, and the marking(s) corrected.

5.   DETAILED REQUIREMENTS

5.1   Marking Method Selection Factors. Data Matrix symbol marking method selection is influenced by a number of different factors. These factors need to be analyzed closely by the user's engineering department to ensure that the appropriate marking method is selected. The factors to be considered are summarized as follows:

5.1.1 <u>Part Function</u>. Part function is an extremely important consideration in the marking method selection process. Non-intrusive marking methods are recommended for parts used in safety critical applications, i.e., parts whose failure could result in hazardous conditions. Safety critical parts applications include, but are not limited to:

- Aircraft engines and control systems
- Handling systems
- High pressure and high stress systems
- Nuclear, biological or chemical containment systems
- Pyrotechnic systems

The use of intrusive markings in safety critical applications requires the written approval of the appropriate NASA engineering or technical representatives.

5.1.2 <u>Part Geometry</u>. Flat surfaces are preferred over curved surfaces for marking. When it is necessary to apply Data Matrix symbol markings to cylindrical shaped parts (both concave or convex), a rectangular symbol should be applied that is sized to fit within the reflective band of light that emanates from the spine of the curve (or 5 percent of the circumference). This band of light typically occupies 16 percent of the diameter of the curve under normal room light and can increase in size under bright light conditions. Figure 3 illustrates the proper method for marking curved surfaces.

Area of high reflectivity
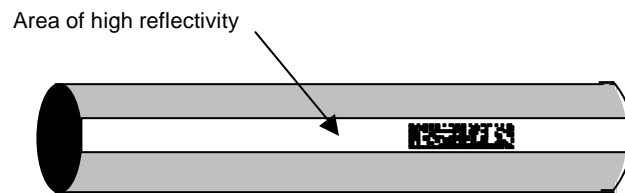
<u>FIGURE 3. Proper Placement of Data Matrix Symbols on a Curved Surface</u>

Highly polished metal surfaces (RMS 0 to 8) should be textured (reference 5.2.4) to reduce glare prior to marking. The textured area should extend one symbol width beyond the borders of the marking as illustrated in Figure 4.

Textured Patched Applied to highly reflective Surface to Reduce Glare
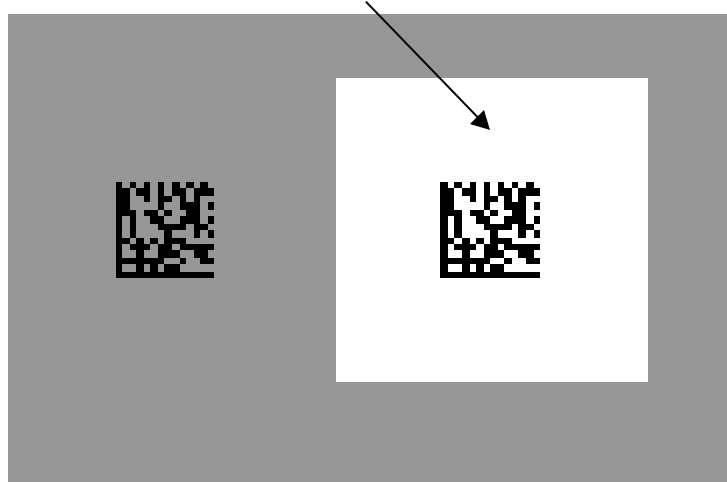
FIGURE 4. Textured Patch Applied to Reduce Glare

5.1.3 Part Size. Part size does not become a factor in 2-D Symbol marking until the available marking area is reduced to below 1/4-inch (6.35 mm) square. Below this level, the number of marking options is reduced significantly. Table I provides a listing of marking methods categorized by marking size.

TABLE I. Required Marking Area for Data Matrix Identification Symbols

Marking Method	Square Inches (mm)				
	Smaller than 1/8 (3.18)	1/8 - 3/1 (3.18-4.7)	13/64 -1/4 (5.16 -6.35)	17/64 -1/2 (6.75-12.)	Over 1/2 (12.7)
Abrasive Blast				■	■
Adhesive Dispensing				■	■
Cast, Forge Or Mold					■
Dot Peen			■	■	■
Electro-Chemical Coloring	■	■	■	■	■
Electro-Chemical Etching	■	■	■	■	■
Embroidery					■
Engraving/Milling			■	■	■
Laser Bonding			■	■	■
Laser Marking	■	■	■	■	■
LaserShot Peening	■	■	■	■	■
LENS			■	■	■
Liquid Metal Jet		■	■	■	■
LISI		■	■	■	
Ink Jet			■	■	■
Silk Screen				■	■
Stencil (Mechanical Cut)				■	■
Stencil (Photo-Process)			■	■	■
Stencil (Laser Cut)		■	■	■	
Note: Sizes predicated on a single ECC200, 14x14 matrix symbol applied using smallest decodable cell size.					

5.1.4 Material Type. The primary determiner in the selection of an appropriate marking method is the material being marked. Table II provides a listing of common marking methods by material type.

5.1.5 Material Hardness. Material hardness does not have an affect on the application of non-intrusive or non-contact marking methods. Hardness does have a direct affect on tool wear where engraving, milling, or stamp impression (dot or lasershot peen) markings methods are used. Tool wear and tool damage should be monitored closely on metals or metal alloys hardened above 35 Rockwell C.

5.1.6 Operating Environment/Age Life. Users should verify that the marking method selected produces a mark that can survive in its intended environment and remain readable for the life cycle of the part. Testing should be structured to simulate expected conditions to ensure that symbol performance expectations will be met. Tests typically used for this purpose are listed in Table III.

TABLE II. Marking Method Selection

MATERIAL TO BE MARKED / MARKING PROCESS	METALLICS								NON-METALLICS								
	Aluminum	Anodized	Beryllium	Carbon Steel	Copper	Cres	Magnesium	Titanium	Ceramics	Glass	Cloth	Painted	Plastics	Rubber	Teflon	Wood	Others
Abrasive Blast	•	•		•	•	•	•	•	•			•	•		•		•
Adhesive Dispensing	•	•	•	•	•	•	•	•	•	•	1	•	•	•		•	•
Cast, Forge Or Mold	•	•	•	•	•	•	•	•	•			•	•				
Dot Peen	•			1	•	1						1	•				
Electro-Chem Coloring	•	•	•	•	•	•	•	•									
Electro-Chem Etching	•	•	•	•	•	•	•	•									
Embroidery											•						
Engraving/Milling	•	•		•	•	•						1	•				
Laser Bonding	•		•	•		•	•	•	•	•			•				
Laser - Short Wave Lengths	•	1	•	•	•		•	•	•	•		1	•	•	•	•	•
Laser Visible Wave Lengths	1	1		•	1	•						1	•				
Laser – Long Wave Lengths		1								•		1				•	
Laser Shot Peening	•	1	2	2	•	2	2	•				1	•				
LENS	•	1	•	•	•	•	•	•									
Liquid Metal Jet	2	2	2	2	2	2	2	2									
LISI	•	2		•	•		2	2									
Ink Jet	•	•	•	•	•	•	•	•	•	•	1	•	•	•			•
Silk Screen	•	•	•	•	•	•	•	•	•	•		•	•	•		•	•
Stencil	•	•	•	•	•	•	•	•	•	•		•	•	•		•	•
Thin Film Deposition	•	•	•	•	•	•	•	•	•	•			•	•			•

• = Acceptable marking process for noted material
1 = Contact Engineering before proceeding
2 = Marking method still under development

TABLE III. <u>Marking Method Test Specifications</u>

Test	Specification Number	Specification Title
Abrasion Resistance	ASTM D-4060-95	Standard Test Method for Abrasion Resistance of Organic Coatings by the Taber Abraser
Adhesion	ASTM D3359-95	Standard Test Methods for Measuring Adhesion by Tape Test
Atmospheric Acid pollution Resistance	ASTM D1308 (with addition of sulfuric acid testing)	Standard Test Method for Effect of Household Chemicals on Clear and Pigmented Organic Finishes
Bending Test	ASTM D522-93	Standard Test Methods for Mandrel Bend Test of Attached Organic Coatings
	ASTM D3794-94	Standard Guide for Testing Coil Coatings
Boiling Water	ASTM D870-92	Standard Practice for Testing Water Resistance of Coatings Using Water Immersion
Chemical Resistance	Not Applicable	1 hour immersion in appropriate chemical
Corrosion Resistance	ASTM B117-97	Standard Practice for Operating Salt Spray (Fog) Apparatus
Hardness	ASTM D3363-92	Standard Test Method for Film Hardness by Pencil Test
Impact	ASTM D2794-93	Standard Test Method for Resistance of Organic Coatings to the Effects of Rapid Deformation (Impact)
Mar Resistance	ASTM D673-93	Standard Test Method for Mar Resistance of Plastics
Thermal	ASTM D2485-91	Standard Test Methods for Evaluating Coatings For High Temperature Service
Transparency	ASTM D1003-95	Standard Test Method for Haze and Luminous Transmittance of Transparent Plastics Transparency
Ultraviolet Exposure	ASTM G53-96	Standard Practice for Operating Light- and Water-Exposure Apparatus (Fluorescent UV-Condensation Type) for Exposure of Nonmetallic Materials
Water Resistance	ASTM D870-92	Standard Practice for Testing Water Resistance of Coatings Using Water Immersion
	ASTM 2247-94	Standard Practice for Testing Water Resistance of Coatings in 100% Relative Humidity
Water Vapor	ASTM E96-95	Standard Test Methods for E96-95 Water Vapor Transmission of Materials
Weathering	ASTM G26-95	Standard Practice for Operating Light-Exposure Apparatus (Xenon-Arc Type) With and Without Water for Exposure of Nonmetallic Materials
Note: ASTM Specifications can be acquired from the American Society For Testing And Materials, West Conshohocken, PA.		

5.1.7 <u>Production Rates (Marking Time)</u>. Process times for marking a symbol on the surface of a part are affected by a variety of factors including, but not limited to, the following:

- Symbol size
- Symbol density
- Marking device
- Mask or mold production (if required)
- Data input
- Part movement and positioning
- Part holding/clamping (if required)
- Operator proficiency

Given the number of variables to be considered, selection of a marking device based on speed must be accomplished on a case-by-case basis.

5.1.8 <u>Surface Color</u>. Dark colored markings are generally applied to light surfaces and light markings applied to dark surfaces. The minimum contrast difference between the symbol and its substrate should not be less that 20 percent as shown on a standard gray scale comparator (see Figure 5).
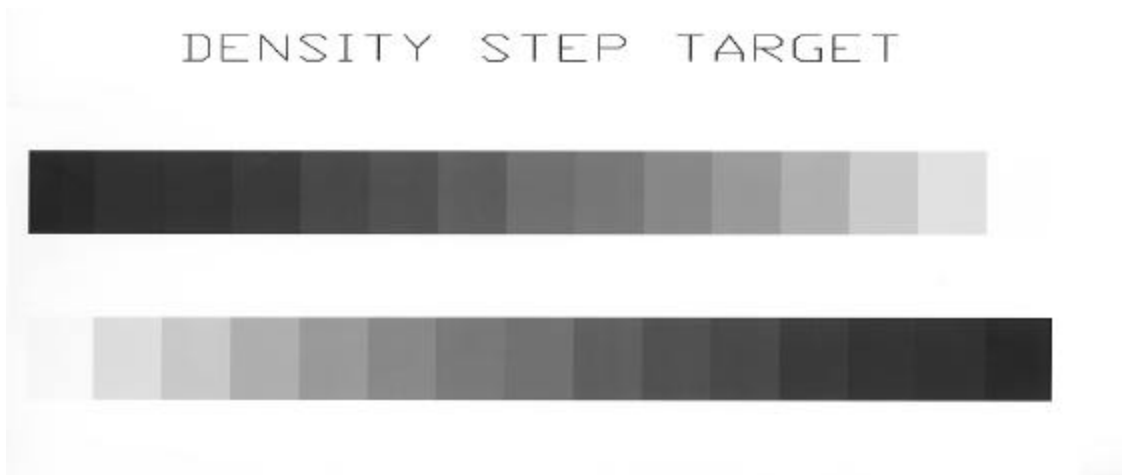
FIGURE 5. <u>Typical Gray Scale Comparator</u>

5.1.9 <u>Surface Roughness/Finish</u>. Symbol marking should be limited to surface roughness levels averaging between 8 and 250 micro-inches (millionth of an inch [0.0000254 mm]), regardless of marking method selected (reference Table IV). Surfaces that fall outside of acceptable surface roughness levels should be resurfaced as defined in section 5.2 or marked with labels, tags, or identification plates (Figures 6 and 8).
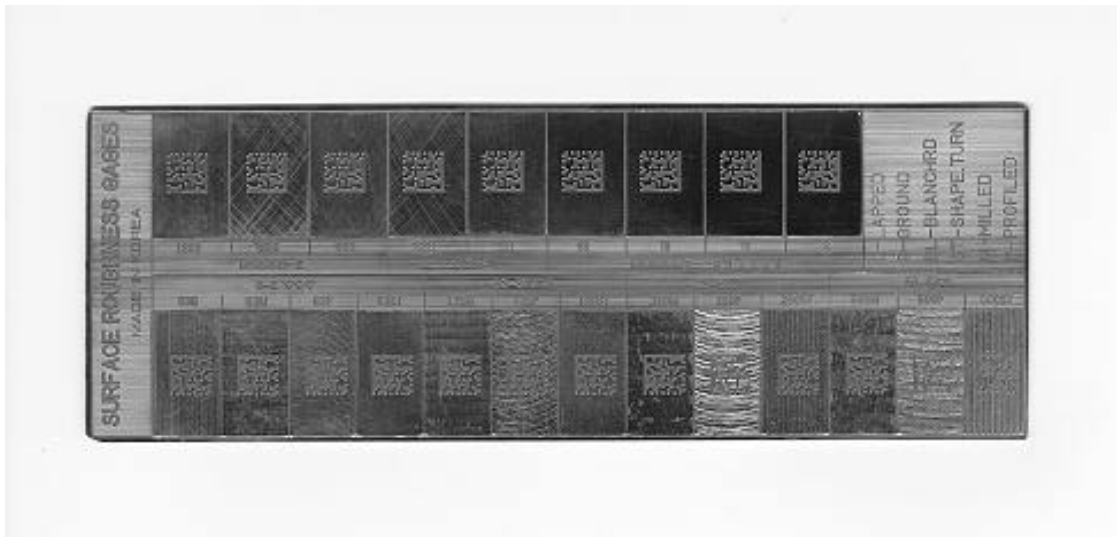
FIGURE 6. <u>Typical Microfinish Comparator</u>

TABLE IV. Ranges of Average Surface Roughness by Processing Method

Processing Category	Processing Method	Roughness Average (Ra) μin.											
		1	2	4	8	16	32	63	125	250	500	1000	2000
Machining	Lapped												
	Ground												
	Blanchard												
	Shape Turned												
	Milled												
	Profiled												
Nonabrasive Finishing													
	EDM												
	LBM												
Blasting	Grit blasting												
	Sand Blasting												
	Shot Peening												
Cast Surfaces	Die												
	Investment												
	Shell Mold												
	Centrifugal												
	Permanent Mold												
	Non-ferrous Sand												
	Ferrous Green Sand												

Optimum Data Matrix Marking Range

Cast surfaces present a unique symbol decoding challenge because the surface irregularities (pits) create shadows that can be misinterpreted by the decoding software as dark data cells. Consequently, individual data cells in the symbol must be larger than the surface irregularities so that the decoding software can differentiate between the two features. The data cells contained in the symbol must be increased in size in direct proportion with the average surface roughness-level to ensure successful decoding. Figure 7 and Table V provide a formula and minimum cell size restrictions developed to aid in determining minimum symbol sizes to be used on cast surface. Otherwise the area to be marked must be treated to provide a smoother substrate for the mark.

Minimum Cell Size vs. Average Roughness Level

Cell Size = (6E -05 x Roughness Level) + 0.0067
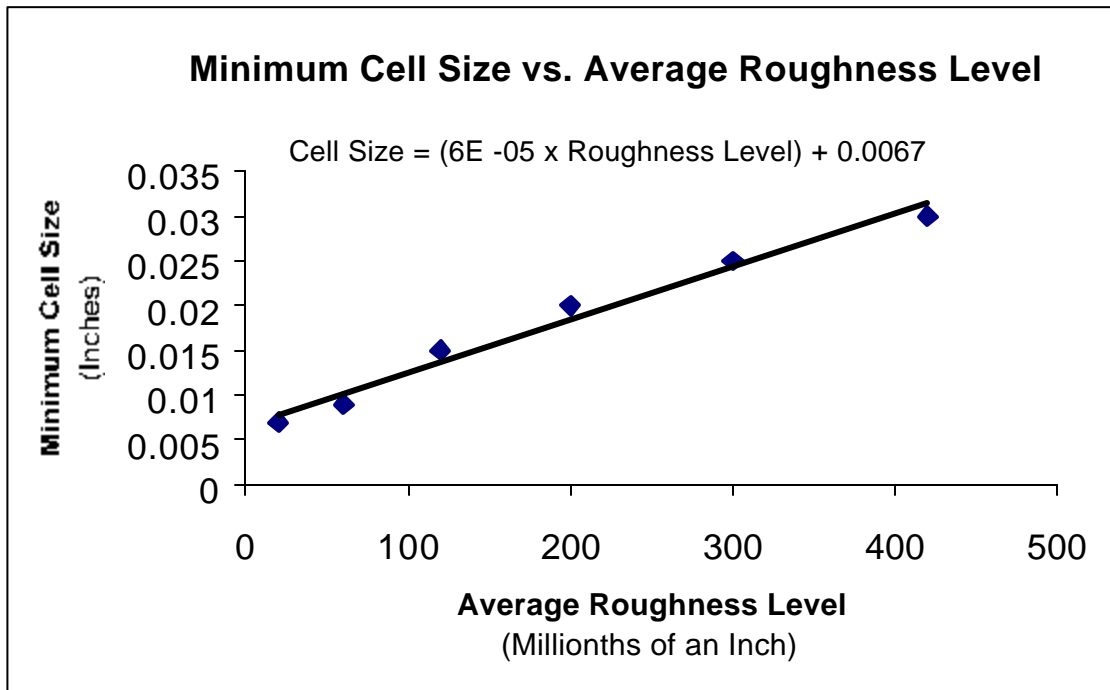

FIGURE 7. <u>Minimum Cell Size vs. Average Roughness Level</u>

TABLE V. <u>Minimum Readable Cell Size by Roughness Level</u>

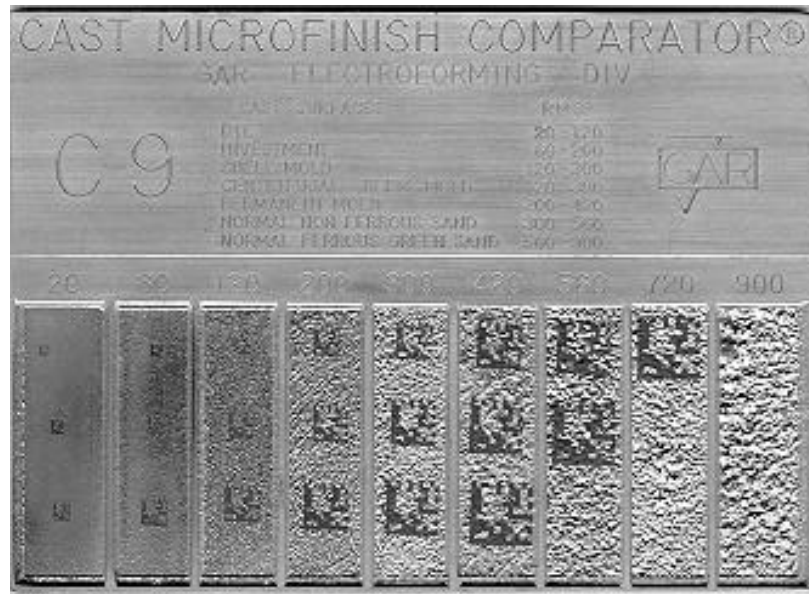| Average Roughness Level (millionths of an inch [0.0000254mm])	Minimum Cell Size (Inches)
20	0.01 (0.19 mm)
60	0.01 (0.23 mm)
120	0.02 (0.38 mm)
200	0.02 (0.51 mm)
300	0.03 (0.64 mm)
420	0.03 (0.76 mm)

FIGURE 8. Comparator Showing Relationship Between Cell Size and Cast Surface Roughness

5.1.10 Surface Thickness. Surface thickness must be taken into account when applying intrusive markings to prevent deformation or excessive weakening of the part. The degree of thickness required for intrusive marking is directly related to the heat, depth, or force applied. In most applications the marking depth should not exceed 1/10 the thickness of the part (10x mark/ etch). Table VI defines the maximum (practical) marking depth that can be obtained using intrusive marking methods. Part thickness is generally not a consideration when marking applying non-intrusive markings.

TABLE VI. Minimum Recommended Substrate Thickness By Marking Method.

Marking Method	Maximum Marking Depth	Minimum Part Thickness
Laser Bonding	Surface Mark	0.001-inch (0.03 mm)
Electro-Chemical Coloring	0.0002-inch (0.06 mm)	0.002-inch (0.05 mm)
Abrasive Blast	0.0003-inch (0.08 mm)	0.003-inch (0.08 mm)
Acid Etch – Stencil	0.0005-inch (0.01 mm)	0.005-inch (0.13 mm)
Chemical Coloring – Stencil	0.001-inch (0.03 mm)	0.010-inch (0.25 mm)
Laser Annealing	0.001-inch (0.03 mm)	0.010-inch (0.25 mm)
Laser Shotpeening	0.002-inch (0.05 mm)	0.020-inch (0.51 mm)
Electro-Chemical Etch	0.002-inch (0.05 mm)	0.020-inch (0.51 mm)
Laser Etch	0.003-inch (0.08 mm)	0.030-inch (0.76 mm)
LISI	0.004-inch (0.10 mm)	0.040-inch (1.02 mm)
Dot Peen	0.004-inch (0.10 mm)	0.040-inch (1.02 mm)
Laser Engraving	0.005-inch (0.13 mm)	0.050-inch (1.27 mm)
Micro-Milling	0.125-inch (3.18 mm)	1.250-inch (31.75 mm)

5.2 <u>Marking Surface Preparation</u>. Prior to marking, operators are required to determine if surface preparation is required. This analysis should address:

- Surface finishes that cause excessive amounts of shadowing and/or glare
- Surfaces that do not provide the necessary contrast for decoding
- Safety critical parts that can not be marked using intrusive marking methods
- Materials that are not conducive to marking with the users preferred marking method

The most common methods utilized to prepare surfaces for marking are additives and coatings.

5.2.1 <u>Additives</u>. Specialized additives can be mixed with metal alloys and thermoplastic formulations to enhance and optimize marking contrast. These additives increase the ability of the material to absorb specific wavelengths of laser light, but do not generally affect overall material performance.

5.2.2 <u>Coatings</u>. Coatings are used to modify a part surface to improve their characteristics and/or provide corrosion protection. Coatings can be utilized to aid part marking by:

- Smoothing rough surfaces to reduce the effects of shadowing
- Providing contrast for part surfaces that fall within gray scale mid-range
- Dulling highly polished surfaces to reduce glare
- Providing a surface that can be removed with intrusive markings to expose a substrate of contrasting color
- Serving as a media for marking using a stencil as a mask

The most commonly used processes to coat surfaces prior to marking are:

5.2.2.1 <u>Dip, Barrier and Conversion Coating</u>. Dip, barrier, and chemical conversion coating is a term that encompasses a family of processes used to prevent corrosion. These coating processes include:

- Anodizing
- Babbitting
- Ceramic Coatings and Linings
- Chromate Conversion Coatings
- Elastomeric Coatings for Automotive Plastics
- Electrodeposited Coatings
- Hot Dip Coatings
- Hot Dip Galvanized Coatings
- Painting
- Phosphate coatings
- Porcelain enameling
- Rust Preventative Compounds

5.2.2.2 Laser Induced Surface Improvement (LISI). LISI is a laser process utilized to instill stainless properties to carbon steel. The process differs from laser bonding in that the coating material is mixed with the substrate to form an improved alloy with high corrosion resistant properties. The process can also be used to improve the wear characteristics of aluminum surfaces. LISI treated surfaces can be discolored or removed to form a representation of a symbol.

5.2.2.3 Plating and Electroplating. Plating and electroplating processes are divided into two categories: Electrodeposition and Nonelectrolytic deposition processes. These processes associated with each of these categories are listed as follows:

Electrodeposition.

- Cadmium Plating
- Copper and Copper Alloy Plating
- Chromium Alloy Plating
- Decorative Chromium Plating
- Electroforming
- Gold Plating
- Indium Plating
- Industrial (Hard) Chromium Plating
- Iron Plating
- Lead Plating
- Multi-Layer Alloy Plating
- Nickel Plating
- Platinum-group Plating
- Pulsed-Current Plating
- Selective (Brush) Plating
- Silver Plating
- Tin and Tin Alloy Plating
- Zinc Plating

Nonelectrolytic.

- Electroless Alloy Plating
- Electroless Copper Plating
- Electroless Gold Plating
- Electroless Nickel Plating
- Mechanical Plating

5.2.2.4 Vacuum Controlled-Atmosphere Coating and Surface Modification Processes. Vacuum and controlled atmosphere coatings is a general term that encompasses Thermal Spray, Chemical Vapor Deposition, Physical Deposition, Diffusion, and Pulsed-Laser Deposition processes. This family of processes is used to modify surfaces by depositing material to part surfaces that is subsequently marked. Vacuum controlled-atmosphere coatings and surface modification processes can be used as a media application method for use with stencil marking.

5.2.3 Machining. Machining is normally accomplished to bring the average surface roughness level of the rough parts to under 250 micro-inches. Reader tests have proven that surfaces rougher than 250 micro-inches produce shadows that adversely affect hand-held reader performance when using symbols in the micro to standard size ranges (1/6 inch (4.23 mm) to 1/2-inch (12.7 mm) square). The most commonly used machining methods used for surface smoothing are:

5.2.3.1 Blanchard (Ground). Grinding is a process to remove material from a part with a grinding wheel or abrasive belt.

5.2.3.2 Lapping. Lapping Is performed by rubbing two surfaces together, with or without abrasives, for the purpose of obtaining extreme-dimensional accuracy or superior *surface finish*.

5.2.3.3 Milling. Milling is performed using a rotary tool with one or more teeth that engage the part and remove material as the part moves past the rotating cutter.

5.2.3.4 Profiling. Profiling is a milling process that duplicates external or internal profiles in two dimensions. A tracing probe follows a two-dimensional template and, through electronic or air actuated mechanisms, controls the cutting spindles in two mutually perpendicular directions. The spindles – usually more than one – are set manually in the third dimension.

5.2.3.5 Shape Turning. Shape turning is a process designed to remove material by forcing a single-point cutting tool against the surface of a rotating workpiece. The tool may or may not be moved toward or along the axis of rotation while it cuts away material.

5.2.4 Texturing. Texturing is commonly used to roughen surfaces in advance of marking to reduce the amount of glare emanating from the parts surface. Glare has been shown to have an adverse affect on a 2-D readers ability to image and decode symbols of any size.

Surface texturing should bring the surface finish to an average roughness level above eight micro-inches as defined by ASA B46-1962 and MIL-STD-10A. Texturing of part surfaces in advance of marking is normally performed by:

5.2.4.1 Abrasive Blast. A process for finishing by means of an abrasive directed at high velocity against a part. Abrasive blasting methods include grit blasting, sandblasting, and shot blasting.

5.2.4.2 Electrochemical Machining (ECM). Controlled metal removal by anodic dissolution. Direct current passes through a flowing film of conductive solution that separates the part from the electrode/toll. The part is the anode and the tool is the cathode.

5.2.4.3 Electro Discharge Machining (EDM). Metal removal by rapid spark discharge between polarity electrodes, one on the part and the other the tool, separated by a gap distance of 0.0005 to 0.035 inches (0.013 to 0.89 mm). The gap is filled with dielectrical fluid and metal particles, which are melted, in part vaporized, and expelled from the gap.

5.2.4.4 Laser Beam Machining (LBM). Lasers are used to texture surfaces by melting the surface to refine its appearance.

5.2.5 <u>Cleaning</u>. Cleaning processes used for removing soils and contamination are varied, and their effectiveness depends on the requirements of the specific application. In selecting a metal cleaning process, many factors must be considered, including:

- The nature of the soil to be removed
- The substrate to be cleaned (i.e., ferrous, non-ferrous, etc.)
- The importance of the condition of the surface to the end use of the part
- The degree of cleanliness required
- The existing capabilities of the available facilities
- The environmental impact of the cleaning process
- Cost considerations
- The total surface area to be cleaned
- Effects of previous processes
- Rust inhibition requirements
- Material handling factors
- Surface requirements of subsequent operations, such as phosphate conversion coating, painting, or plating

The most commonly used cleaning processes used in conjunction with DPM are:

5.2.5.1 <u>Acid Cleaning</u>. Acid cleaners more diluted than acid pickling solutions are effective for removing light, blushing rust, such as the rust that forms on ferrous metal parts in storage under conditions of high humidity or short-time exposure to rain. Acids deoxidizing solutions, specifically designed for use on aluminum remove oxides, should be used before electroplating or chemical coating. Various organic acid-based solutions, such as citric acid, are used to remove rust from stainless steels, including the 400 series and the precipitation hardening steels.

5.2.5.2 <u>Alkaline Cleaning</u>. Alkaline cleaning is a commonly used method for removing a variety of soils from the surface of metals. Soils removed by alkaline cleaning include oils, grease, waxes, metallic fines, and dirt. Alkaline cleaners are applied by either spray or immersion facilities and are usually followed by a warm water rinse. A properly cleaned metal surface optimizes the performance of a coating that is subsequently applied by conversion coating, electroplating, painting, or other operations. The main chemical methods of soil removal by alkaline cleaner are saponification, displacement, emulsification and dispersion, and metal oxide dissolution.

5.2.5.3 <u>Compliance Wipe</u>. Compliance wipe solvents are used to remove contaminants from parts before they undergo manufacturing operations that require clean surfaces, such as bonding, sealing, painting, welding, plating, specialized surface treatment procedure, and others. Traditional wipe solvents include:

- Methyl ethyl ketone
- Methtl isobutyl ketone
- Trichloroethene (trichloroethylene)
- Tetrachloromethane (perchloroethylene)
- 1,1,1,-trichloroethane (methyl chloride)
- Acetone
- Toluene
- Dichloromethane (methylene chloroform)

- Tetrachloromethane (carbon tetrachloride)
- Benzene
- Xylene
- Ethylene glycol ethers
- Diethylene glycol ethers
- 1,1,2-troichloro-1,2,2-trifluoroethane (CFC-113)
- Combination of these materials

The U.S. Environmental Protection Agency (EPA) has classified these materials as being either hazardous air pollutants or ozone layer depleting substances that have been or will be banned from use in the near future. Innovative methods will be required to develop wipe solvent materials that will meet EPA requirements for the emission of volatile organic compounds, the reduction or elimination of hazardous air pollutants, and the elimination of ozone layer depleting substances. Alternative materials are identified in MIL-C-38736.

Other solvents are obtainable under the following commercial brand names: Exxon Coporation's Isopar C, Isopar E, Isopar G, Isopar, H, Isopar, K, Isopar L, Isopar M, Isopar, V, Axarel 9100 (isoparaffins) and 3M company's PF-5050, PF-5052, Pf,5060, PF 5070 and PF5080 (perflurocarbons).

    5.2.5.4 <u>Emulsion Cleaning</u>. Emulsion cleaning is an industrial cleaning process that uses an organic solvent as the main active agent. The solvent is usually a hydrocarbon of distilled petroleum dispersed in water. The emulsion, which alone is potentially volatile, is suspended in a nonvolatile aqueous vehicle. Most emulsion cleaners include emulsifying agents, and some are aided by surfactants. Emulsion cleaners are generally used in situations where alkaline or acid cleaners are not applicable.

    5.2.5.5 <u>Mechanical Cleaning Systems</u>. Mechanical cleaning systems are available for most industrial production applications to remove contaminants and prepare the work surface for subsequent finishing or coating operations. Typical uses include:

- Removing rust, scale, dry solids, mold sand, ceramic shell coatings, or dried paint
- Roughening surfaces in preparation for bonding, painting, enameling, or other coating substances.
- Removing large burrs or weld spatter
- Developing a uniform surface finish, even when slightly dissimilar surfaces are present
- Removing flash from rubber or plastic molding operations
- Carving or decorative etching of glass, porcelain, wood, or natural stone such as granite or marble.

The types of parts that can be mechanically cleaned are:

- Ferrous and nonferrous castings
- Forgings or stampings
- Steel plate, strip, or structural shapes
- Weldments and fabrications of ferrous and nonferrous materials
- Aluminum, magnesium, or zinc permanent mold or diecast items
- Thermoplastic or thermoset plastics
- Steel bar stock and wire rod

- Precision molded rubber parts
- High-alloy dies and molds for rubber, plastic, glass, or metal parts
- Miscellaneous exotic parts

Mechanical cleaning systems use various types of abrasive materials that are energized or propelled against the work surface or part using one of the following methods:

- Airless centrifugal blast blade- or vane-type wheels
- Compressed air, direct-pressure dry blast nozzle systems
- Compressed-air, indirect-suction (induction) wet or dry blast nozzle systems
- Aggressive vibratory systems
- Media tumbling systems
- Part-on-part tumbling system

5.2.5.6 <u>Molten Salt Bath Cleaning</u>. Molten salt baths are anhydrous, fused chemical baths used at elevated temperatures for a variety of industrial cleaning applications. Among the more common uses of these baths include:

- Removal of organic polymers and coatings
- Dissolution of sand, ceramic, and glassy materials
- Stripping of plasma carbide coatings

In addition, molten salt baths may be used to pretreat cast iron surfaces before brazing, bonding or marking operations. Molten salt baths for cleaning applications are chemically active or reactive fluids with unique process capabilities. The chemistry involved during various cleaning applications ranges from simple dissolution of contaminants to more complex reactions involving the thermochemical oxidation of organics and the electrolysis of molten salts.

5.2.5.7 <u>Pickling and Descaling</u>. Pickling is the most common of several processes used to remove scale from steel surfaces. The term Pickling refers to the chemical removal of scale by immersion in an aqueous acid solution. The process originated in the late 1700s when sheets of steel were descaled by immersion into vats of vinegar. Wide variations are possible in the type, strength, and temperature of the acid solutions used, depending on the time constraints (batch versus continuous operations), and the thickness, composition, and physical nature (cracks) of the scale. Pickling is applicable for many types of forgings and castings, for merchant bar, blooms, billets, sheet, strip, wire, and for tubing.

5.2.5.8 <u>Solvent Cold Cleaning and Vapor Degreasing</u>. Solvent cleaning is a surface preparation process that is especially adept at removing organic compounds such as grease or oil from the surface of a metal. Most organic compounds are easily solubilized by organic solvent and removed from the parts. In some cases, solvent cleaning before other surface preparations can extend the life of cleaning operations and reduce costs. Solvent cleaning is often used to prepare parts for marking. Before marking, solvent cleaning is usually followed by an alkaline wash or another similar process that provides a hydrophilic surface. Solvent cleaning can also be used to remove water from parts marked with platings, laser bonding, or similar marking processes.

Solvent cleaning can be accomplished in room-temperature baths or by using vapor-degreasing techniques. Room temperature solvent cleaning is referred to as cold cleaning. Vapor degreasing is the process for cleaning parts by condensing solvent vapors of a solvent on parts. Parts may also be degreased by immersion in the hot solvent as well as by exposure to the solvent vapor. Drying is accomplished by evaporating the solvent from the parts as they are withdrawn from the hot solvent vapor. In cold cleaning, the parts are dried at room temperature or by the use of external heat, centrifuging, air blowing, or an absorptive medium. The use of many industrial solvents is being severely restricted because of health, safety, and environmental concerns.

5.2.5.9 <u>Ultrasonic Cleaning</u>. Ultrasonic cleaning (Ref. STM G-131) involves the use of high-frequency sound waves (above 18kHz) to remove a variety of contaminates from parts immersed in aqueous media. The contaminants can be dirt, oil, grease, buffing/polishing compounds, and mold release agents, just to name a few. Materials that can be cleaned include metals, glass, ceramics and so on. Ultrasonic agitation can be used with a variety of cleaning agents. Ultrasonic cleaning is powerful enough to remove tough contaminants, yet gentle enough not to damage the substrate. It provides excellent penetration and cleaning in the smallest crevices and between tightly spaced parts in a cleaning tank.

5.2.5.10 <u>Classification and Selection of Cleaning Processes</u>. Classification and selection of cleaning processes are defined in ASM Surface Engineering Handbook, Vol. 5.

5.2.5.11 <u>Cleanliness Verification</u>. Appropriate levels of cleanliness can be verified using the test methods defined in ASTM G-120 and ASTM G-144.

5.3 <u>Marking Methods</u>. Direct part marking (DPM) is generally suggested in applications where:

- Traceability is required after the product is separated from its temporary identification
- The part is too small to be marked with bar code labels or tags
- The part is subjected to environmental conditions that preclude the use of add-on identification means
- Identification is required beyond the expected life of the part to preclude further use

DPM can be broken down into two primary categories: non-intrusive and intrusive. Figures 9 and 10 provide examples of cross sectional views of the various direct part markings described in this section.

5.3.1 <u>Non-intrusive Marking Methods</u>. Non-intrusive markings, also known as additive markings, are produced as part of the manufacturing process or by adding a layer of media to the surface using methods that have no adverse effect on material properties. These methods include:

- Adhesive dispensing
- Cast, Forge, or Mold
- Liquid Metal Jet
- Ink Jet
- Silk Screen Markings
- Stencil Markings
- Thin Film Deposition
- Laser Bonding
- LENS

Additive Markings – Adhesive dispensing, Ink Jet, Laser Bonding, LENS, Liquid Metal Jet, Silk Screen, Stencil, and Thin Film Deposition

Raised Markings – Cast, Forge, or Mold
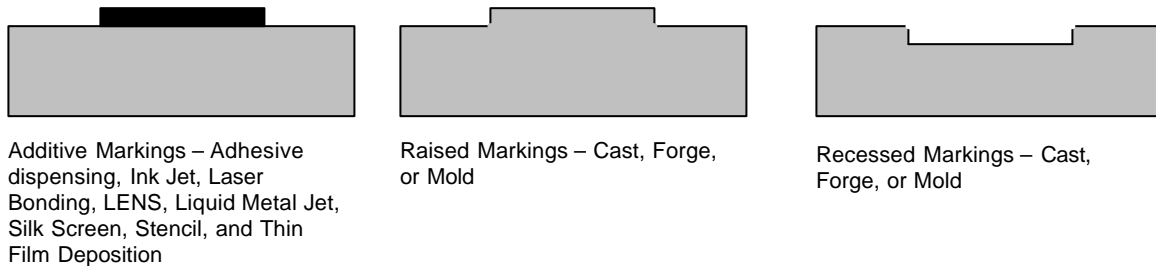
Recessed Markings – Cast, Forge, or Mold

FIGURE 9. Data Matrix Symbol Non-Intrusive Marking Cross Sections

5.3.2 Intrusive Marking Methods. Intrusive markings that alter a part's surface (abrade, cut, burn, vaporize, etc.) are considered to be controlled defects and if not applied properly can degrade material properties beyond a point of acceptability. Consequently, some intrusive markings, especially laser, are generally not used in safety critical applications without appropriate metallurgical testing. Typical intrusive marking methods include:

- Abrasive Blast
- Direct Laser Marking
- Dot Peen (Stamp Impression)
- Electro-Chemical Etching (electrolytic surface coloring or metal removal processes)
- Engraving/Milling
- Fabric Embroidery
- LaserShot Peening

Textured Marking – Micro-Abrasive Blast

Discolored Markings – Chemical Coloring, Electro-Chemical Coloring (AC) and Laser Coloring

Etched Markings – Electro-Chemical Etch (DC) and Laser Etch

Recessed Markings – Engraving and Milling

Recessed Markings – Laser Engraving

Recessed/Etched Marking Backfilled to Provide Contrast

Impression Stamp Marking – Dot & LaserShot Peening

Recessed Marking Coated to Prevent Accumulation of Foreign material or Corrosion

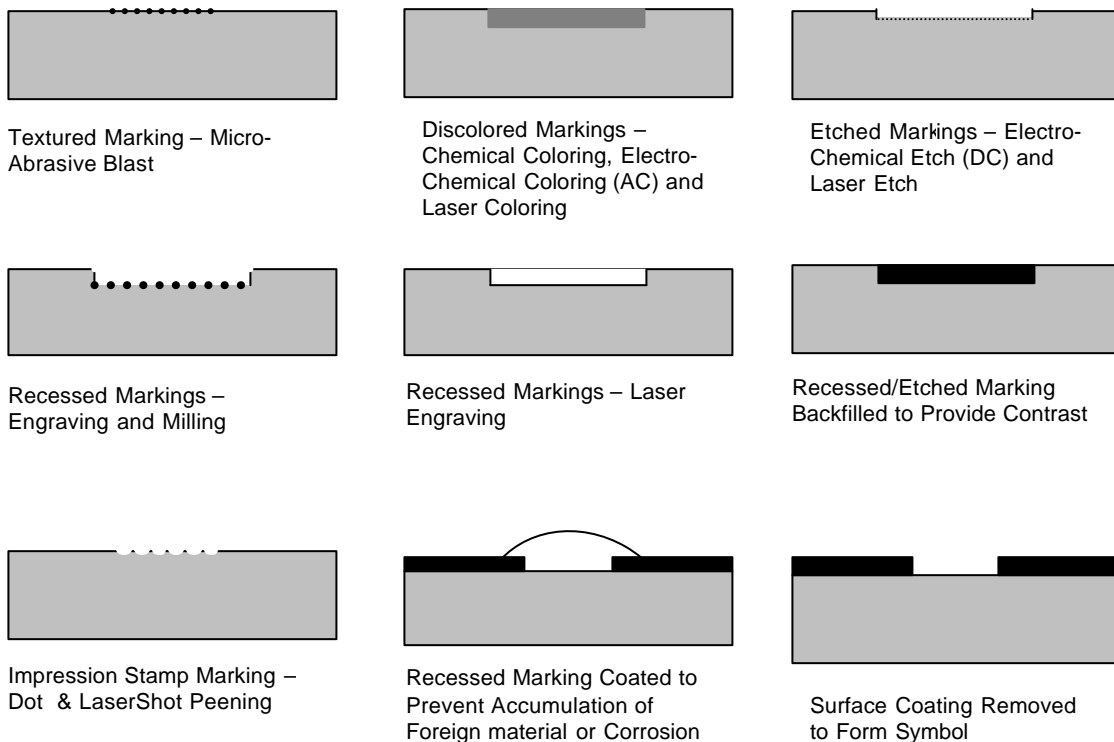Surface Coating Removed to Form Symbol

FIGURE 10. Data Matrix Symbol Intrusive Marking Cross Sections

5.3.3 <u>Marking Method Requirements</u>. The marking method selected depends on the NASA program or project requirements. Material degradation and hazard analysis studies may be required for safety critical part applications. Review by the applicable engineering and program/project offices to ensure that product integrity is not compromised may be required. Detailed instructions related to the application of DPM methods are contained in NASA HDBK-6003A, A*pplication of Data Matrix Identification Symbols to Aerospace Parts Using Direct Part Marking Methods/Techniques.*

5.4 <u>Marking Locations</u>. Data Matrix decoding software require a minimum of one data cell width of clear space (quiet zone) around the entire periphery of the symbol to be read successfully. However due to variations in surface finish, this requirement has been extended to 10% of the longest symbol side on NASA programs. In addition to this requirement, manufacturers often impose additional marking location restrictions within their drawings and/or specifications. These documents take into consideration the affect that the markings have on the product's form, fit, and function. They also address symbol positioning as it relates to marking device clearance and reading during manufacture and after assembly. Unless otherwise directed, Data Matrix symbols should not be applied in the following locations:

- High traffic areas
- Highly polished curved surfaces (RMS 0 to 8)
- In direct air streams (e.g., leading edge of wings, helicopter rotors, exposed portions of turbine blades, etc.)
- Near high heat sources
- Sealing surfaces
- Wearing surfaces

In addition, operators must also take into consideration the affects that adjacent structures have on the reader's illumination source.   Fixed station readers with movable light sources can generally be configured to successfully illuminate symbols placed in recesses or adjacent to protruding structures. These structures, however, can pose a challenge for hand-held readers with fix positioned light sources. Consequently, markings to be read in the field must be positioned so that a sufficient amount of illumination can be projected to the symbol to facilitate reading (see 5.7).

5.5 <u>Re-marking Requirements</u>. This standard has taken into account the material degradation caused by the application of a single human readable and/or Data Matrix symbol identification marking applied using an intrusive marking method. Additional intrusive markings made to obliterate original markings and/or to add additional markings to correct errors or define changes in part configuration may further reduce material properties beyond a point of acceptability. Therefore, additional part identification markings are not permitted without approval of the responsible quality assurance and engineering organizations.

5.6 <u>Protective Coatings</u>. Although they often appear to be permanent, metals are unstable in their service environments and are susceptible to degradation by corrosion. Corrosion occurs when protective mechanisms have been overlooked or have been exhausted, leaving the metal vulnerable to attack by hostile environments. Corrosion control is essential in the aerospace industry. Protective coatings are applied to marked surfaces to protect the marking and prevent corrosion. Intrusive markings applied to a surface that has been previously coated must be re-coated to prevent corrosion in or around the area of the marking.

A protective coating is also required when marks are subjected to wear, frequent handling, or environmental conditions that can damage the mark. The coating must be clear and should provide a protection level equal to or greater than the original protect finish. The coating cannot result in contamination later in the process, during operation or in outer space. Matte finish coatings are preferable over gloss for reading. Typical coatings include, but are not limited to, the following:

5.6.1 <u>Clear Anodize (MIL-A-8625E)</u>. Anodizing is an electrolytic oxidation process in which the surface of the metal, when anodic, is converted to a coating having desirable protective, decorative, or functional properties.

5.6.2 <u>Lacquer (TT-L-50)</u>. Lacquer is a coating formulation based on thermoplastic film-forming material dissolved in organic solvent. The coating dries primarily by evaporation of the solvent. Typical lacquers include those based on lac, nitrocellulose, other cellulose derivatives, vinyl resins, acrylic resins, and so forth. Softer deposits are described as *varnishes* or *gums*.

5.6.3 <u>Thin Film Deposition</u>. Thin film deposition is a process involving the deposition of a clear metal film onto a substrate in a vacuum by metal evaporation techniques.

5.7 <u>Reading Requirements.</u> The various data matrix readers on the market vary in their ability to read the data matrix on highly reflective or rough surfaces. The different reader types also operate with maximum effectiveness at varying distances from the surface containing the mark. Near contact of touch readers may be hindered by protruding structures or not be able to focus on marks placed with recesses. Other readers that operate from a distance to the surface may similarly have their illuminators shadowed when viewing marks placed in recessed areas or surrounded by protrusions. Therefore the proper placement of the mark will be a tradeoff between the areas on the part that may be conveniently marked and accessed to the areas on which the data matrix reader will operate effectively. Thus, the marking area, reflectivity and roughness of the surface chosen for marking should always take into account the properties and limitations of the data matrix reader types to be used. In general, this will lead to preferring a less reflective and smoother surface that is not deeply recessed or near protrusions.

5.8 <u>Reading Test Standard</u>. Data Matrix symbol markings should be verified prior to being applied to production hardware. High contrast markings can be verified using commercially available software designed specifically for this purpose. Raised or recessed markings must be measured to ensure that height or depth requirements are met. This is typically accomplished using non-contact laser based (non-optical) depth measurement devices designed for this purpose. Symbol verification shall be accomplished using the readers planned for use on the program/project and under lighting conditions that closely mimic the users operating environment. The verification software can be utilized to establish the marking parameters required to establish an "A" grade prior to initiation of production marking. The software should be continuously monitored for grade reductions that are an initiator of machine, tooling or fixture degradation. Marking shall be discontinued when a grade of "C" is reached and maintenance performed to reestablish an optimum mark.

6. NOTES

6.1. <u>Intended Use</u>

6.2 <u>Key Word Listing</u>

Configuration management
Data matrix
Direct mart marking
License tag number
Machine-readable code
Part cleaning
Part finish
Part identification
Part marking
Part tracking
Protective coating

DOCUMENT HISTORY LOG, NASA-HBK-6002

Status (Baseline/ Revision/ Canceled)	Document Revision	Effective Date	
Baseline		7-02-2001	Baseline Release
Revision	A	6-17-2002	Incorporates metric unit equivalent in parentheses beside all English measurement units.
			Section 4.1 has a statement added that when measurement terms are expressed, English units will be used as the "Primary" expression and Metric units will the "Secondary" expression, shown in parentheses beside the English units.
			Section 4.1 has a statement added that data matrix symbols that are applied to the substrate of a part and subsequently covered with paint, foam, and other protective coatings shall be applied by the same methods identified in this Standard and its related Handbook, NASA-HDBK-6003A, *Application of Data Matrix Identification Symbols to Aerospace Parts Using Direct Part Marking Methods/Techniques.*
			Section 4.2 has modified text that changes the data content order from part number-CAGE-serial number to CAGE-part number-serial number, making this Standard consistent with MIL STD 130 and other direct part marking standards. It also defines that an asterisk will be used to separate those data fields when ASCII format is used and a dash when human readable identification is used.
			Figure 1 was rearranged to be consistent with the text of Section 4.2.
			Foreword was shortened and new Section Background added.