N94- 32444

BEGINNING THE 21ST CENTURY
WITH ADVANCED AUTOMATIC PARTS IDENTIFICATION (API)

Fred Schramm
Technology Utilization Office
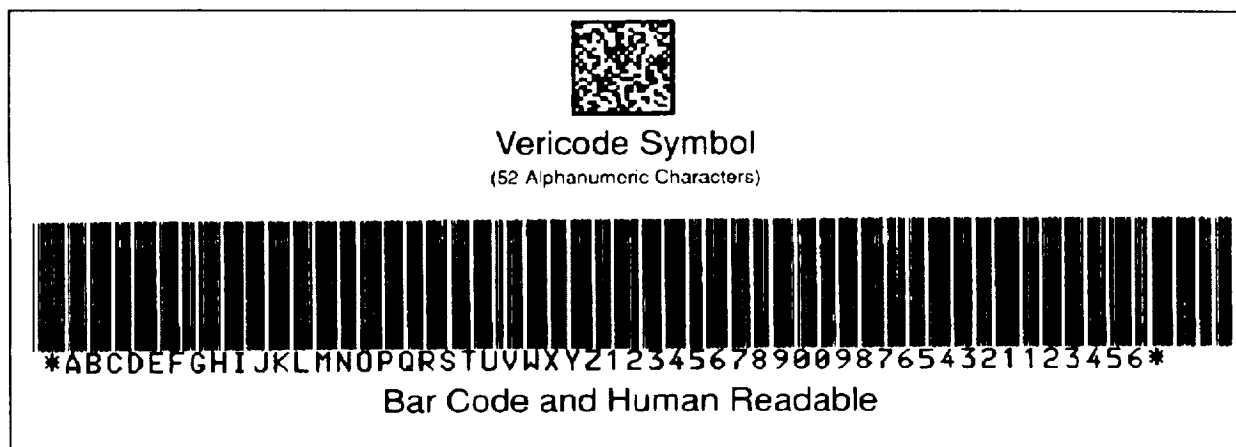**Marshall Space Flight Center, AL 35812**

Don Roxby
Rockwell International
555 Discovery Drive
Huntsville, AL 35806

ABSTRACT

Under the direction of the NASA George C. Marshall Space Flight Center, Huntsville, Alabama, the development and commercialization of an advanced Automated Parts Identification (API) system is being undertaken by Rockwell International Corporation. The new API system is based on a variable sized, machine-readable, two-dimensional matrix symbol that can be applied directly onto most metallic and nonmetallic materials using safe, permanent marking methods. Its checkerboard-like structure is the most space efficient of all symbologies. This high data-density symbology can be applied to products of different material sizes and geometries using application-dependent, computer-driven marking devices. The high fidelity markings produced by these devices can then be captured using a specially designed camera linked to any IBM-compatible computer. Application of compressed symbology technology will reduce costs and improve quality, productivity, and processes in a wide variety of federal and commercial applications.

Existing Automated Identification Systems

There are thousands of applications for automatic identification. Although many technologies are available, most currently use bar code systems. Bar codes are one-dimensional systems and are generally attached to products using paper labels or tags, or by incorporating the code onto the product wrapper. This indirect marking approach, while suitable for retail sales, distribution, and other applications that are not paperless, is inadequate for marking products subject to harsh environments and handling. Bar coded paper labels, for example, are not tolerant of heat, cold, rain, wind, abrasion, chemicals, and other unfriendly conditions many products encounter during their life cycles. In addition to the limitations of typical bar code label material, the basic bar code design—long code length, fixed size and lack of error correction—has its own set of limitations when the decoding system attempts to deal with a variety of substrates.

Vericode Symbol
(52 Alphanumeric Characters)

ABCDEFGHIJKLMNOPQRSTUVWXYZ1234567890098765432112345 6
Bar Code and Human Readable

A comparison of VERICODE® and bar code symbologies using the same 52-character string.

SUMMARY

The CADRS system provides a unique solution to the problems of dissimilar and incompatible host systems, was compounded at NASA sites by multi-center and contractor operations. Currently, there are 27 different mainframe systems in widespread use by the space program. Included in this number are NASA specific systems as well as in-house contractor systems. Although, the situation at NASA is unusual it is by no means unique. Commercial industry with multiple legacy systems would find CADRS to be a viable option for data retrieval and dissemination. The system provides a low cost alternative to client/server systems when information retrieval is the primary consideration.

The three sub-systems of CADRS can be operated as a stand-alone system to provide improved data access. The CDD can be used on stand alone workstations to handle technical documents and manuals. Its ability to perform intelligent searches on large documents makes it well suited for reference systems. The ARS system provides techniques to automate standard data retrieval processes. This provides man-hour savings as well as shifting resource intensive tasks to non-peak periods. The Forms Query system provides a low cost graphical interface for performing common queries. These forms allow non-trained personnel to perform a greater percentage of the required data retrievals. Whether using all or a part of CADRS the benefits of the technology are obvious.

REFERENCES

[1]   Gross, D., "Methods and Means Used in Programming Intelligent Searches of Technical Documents", NASA Conference Publication 3189, Volume 2, pp 55-62, 1992.

[2]   Butler, J., "Middleware Needed to Plug Client/Server Holes", Software Magazine, July 1993 v13 n10 pg 55-57.

[3]   Luger, G. and Stubblefield, W., "Artificial Intelligence and the Design of Expert Systems", Benjamin/Cummings Publishing Company, Inc. 1989.

[4]   Minsky, M., "Semantic Information Processing", The Massachusetts Institute of Technology Press, 1968.

[5]   Whittington, R.P., "Database Systems Engineering", Oxford University Press, 1988.

Advanced Automated Parts Identification Systems

Because of inherent limitations of bar code for direct part marking in the aerospace industry, NASA sought a more suitable API technology. In 1991, Rockwell was asked by NASA to initiate a compressed symbology testing program to survey the API industry, evaluate the commercially available products, and choose an approach that would satisfy component marking requirements in the Space Shuttle program. The test program was open to all manufacturers of advanced API systems that met the specific criteria developed for NASA aerospace program applications. These criteria included, but were not limited to, the following:

1. The system software must be capable of producing user-selectable data densities to meet a wide-range of applications, such as six to 30 character-codes.

2. The symbol structure must be conducive to the application of symbols onto metallic and nonmetallic substrates exhibiting a wide range of surface reflectivity and topography, using the permanent hardware marking methods defined by MIL-STD-130 and others.

3. The system must be capable of producing readable, low data-density symbols small enough to apply directly onto electronic components and critical fasteners.

4. The system software must provide symbol damage reconstruction features to overcome the various mechanisms of symbol deterioration that can be expected in aerospace applications, e.g., fading, scratches, gouges, etc.

5. The system must be capable of reading from acute angles of camera and symbol rotation under a variety of environmental conditions.

6. The system must provide the ability to read symbols in remote locations requiring camera portability, e.g., internal vehicle structures, stock yards, launch pads, emergency landing strips, etc.

In August 1991, the newly created Rockwell Huntsville Compressed Symbology Laboratory conducted the initial pretest system screening. Nine different systems were reviewed; all but two were eliminated. The selected systems were two-dimensional (matrix) systems and were subsequently brought on-site for evaluation. The test program that followed resulted in the VeriSystem® being chosen as best suited for an advanced API system for aerospace applications.

VERICODE® System (VeriSystem®) Description

The VERICODE® Symbol, developed by Veritec Inc., Chatsworth, California, is a high data-density, two-dimensional, machine-readable code that can be produced in variable size. The symbol can be applied directly to virtually any material including metal, plastics, glass, paper, etc. and read using a fixed station or portable charged coupled device (CCD) camera. Designed to run on IBM-compatible microcomputers, the VeriSystem® consists of two basic modules: encode, which converts the human-readable code into VERICODE®; and decode, which reverses the translation process.

The encode process converts human-readable data, e.g., serial or inventory tracking number, into a VERICODE® Symbol. The user may specify the data density and the size of the symbol required to fit the available marking space. After the symbol is prepared by the encoding process, it is marked on a part using a marking methodology appropriate for the part's composition and anticipated operating environment. The VERICODE® Symbol can be permanently affixed to virtually any material regardless of shape.

The decode process captures the symbol via CCD camera and then recognizes and converts it. The VeriSystem® can "read" symbols under a wide variety of orientations. Symbols can be rotated up to 360 degrees and tilted up to 80 degrees from the horizontal position. Error detection and correction capabilities of VeriSystem® will salvage as much of the data as possible and identify missing or damaged data. The system also

features data reconstruction that allows for recognition, regeneration, and decoding of damaged symbols. The reconstruction feature allows for recovery up to 40 percent by adding data codes.

Decoded data can be transferred to a host computer via hard wire, radio frequency (RF) or modem. If the decoded data is a component's serial number, the unique number can be used as a key to retrieve life cycle, maintenance, or other information about that particular component from a data base. This decoded data can also be used by computerized inventory, manufacturing, and schedules' subsystems in an organization.

PROGRAM APPLICATIONS AND BENEFITS

The majority of aerospace technologies are product specific and were primarily targeted at solving specific problems using exotic materials, unique processes, and numerous government specifications. However, compressed symbology is a dual-use technology, meaning it has a wide range of applications in both federal and commercial industries. The technology's ability to automate parts identification can improve competitiveness and provide a quick return on investment.

Compressed symbology provides a computer-based foundation for a true closed-loop, fully automated configuration management and accounting system. The VeriSystem® eliminates the need for labels and tags on small components, piece parts and materials; and eliminates manufacturing operations' need for concurrent paper travel, such as work authorization documents that travel with items during fabrication, assembly, checkout, installation, and changeout. The product, and the information about the product, flows together—synchronized. The code logic is virtually tamper proof.

Compressed symbology technology is ideally suited to inventory marking of parts and components in the aerospace, automotive, electronics, and pharmaceutical industries. Incorporation of compressed symbology in computer-based manufacturing, fabrication, and assembly applications can eliminate a major source of errors—data reentry—by eliminating the manual reentry of component identification data. Compressed symbology can add significant value to automated design and manufacturing, configuration management, modular tooling, robotics, and quality control.

## DIRECT PART MARKING—DEVELOPMENT STATUS

Direct part marking has the potential of damaging the substrate, a risk not encountered with indirect marking approaches. The goal of the marking process is to make a readable, durable mark (in essence, a controlled defect) without disturbing the surrounding substrate. A variety of materials, most of which are routinely used in the Space Shuttle program, have been subjected to extensive metallurgy, fatigue, and environmental testing to assess the affects of different marking methods. These tests are used to determine the marking methods and marking device settings that produce the best marks with the least change to the material's surface. Fatigue tests are performed to ensure that the marks do not significantly change material properties and therefore reduce the life of the part. Environmental tests assess the readability of the marks subjected to environmental conditions expected during the life cycle of the material. For example, environmental tests, consisting primarily of long-term exposure to salt spray, are being performed for the Defense Industrial Supply Center on marked fasteners used by the military to test readability.
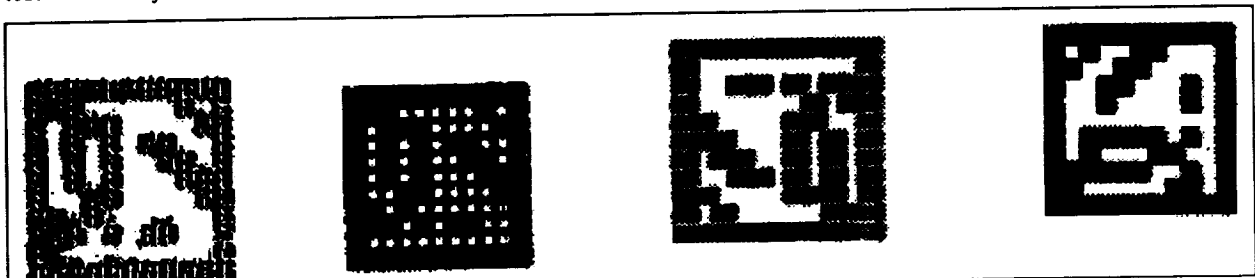
A bar of Aluminum 2024 showing four direct part marking methods. From left to right, dot peen, engraver (backfilled with flat black paint), micro-abrasive, and Nd:YAG laser.

Thirty-three marking methods for applying VERICODE® Symbols were identified, but only six computer-based approaches were selected for testing. The six are:

1. Laser Etch—A highly reliable technology, the laser etch marking method has been in use since 1976. The AB Laser Company Landmark Model 6001 computer-driven Nd:YAG laser marking system can produce quality markings at precise depths by adjusting power, frequency, and speed settings. These adjustments provide the control necessary to apply machine-readable VERICODE® Symbols, human-readable markings, and graphics to most surfaces with a minimum of surface disruption. With current technology, the smallest readable symbol produced by the laser etch marking method is 0.125-inch square.
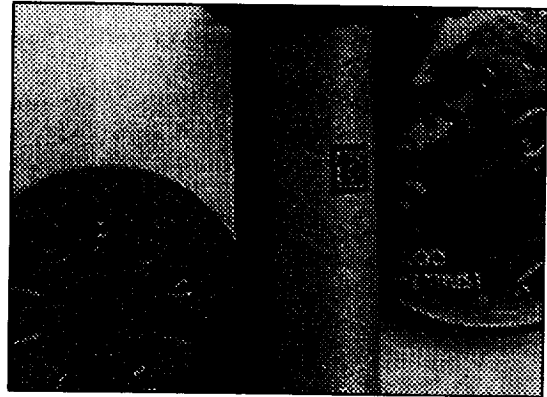
VERICODE® Symbols etched by laser on critical fasteners.

2. Machine Engraving—The Newing-Hall, Inc. model NH-300 computer-driven engraving system is used to remove base material to a prescribed depth and is accomplished using a computer-guided cutting tool. The method is suitable for marking VERICODE® Symbols, human-readable markings, and graphics onto most metallic and nonmetallic substrates used on the Space Shuttle program. Readability of the symbols is contingent upon the contrast between the surface material and engraving. In instances where there is no natural contrast, a backfill material (permanent ink, paint, etc.) is applied to the engraved mark. With current technology, the smallest readable symbol produced by the machine-engraving marking method is 0.125-inch square.

3. Dot Peen—The Wetzel Tool Company Mark V computer-driven dot peen marking system produces machine readable VERICODE® Symbols, human-readable markings, and graphics (logos) on metallic and nonmetallic materials. The system utilizes a computer-operated device that drives a pointed tungsten carbide stylus onto the surface to be marked. The device marks the material by repeatedly striking the surface with the stylus, forming a series of dots (cone shaped recesses). The highly localized, low stress blows deform and stretch the metal surface causing a difference in contrast between the peened and unpeened areas of the part. This difference in contrast can normally be read and decoded by the VeriSystem®. Dot peened materials, which do not naturally provide adequate contrast for decoding, can be enhanced by backfilling the recessed areas with a permanent filler material of contrasting color. With current technology, the smallest readable symbol produced by the dot peen marking method is 0.125-inch square.
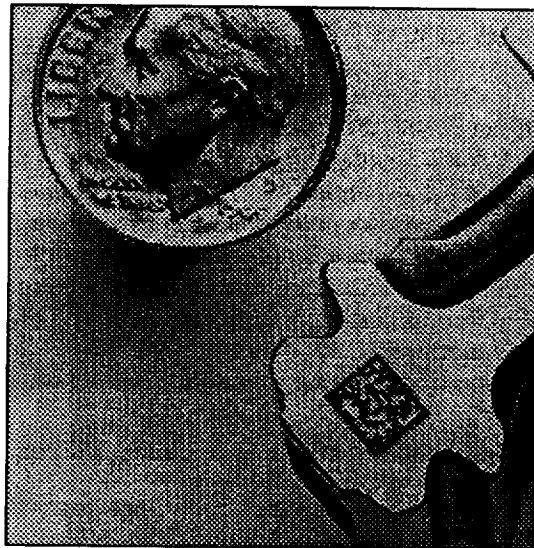

VERICODE® Symbol dot peened onto a turbine blade.

4. Micro-Abrasive—The Comco, Inc. model PR1101-3 computer-driven micro-abrasive system is a miniature "sand" blaster that marks by directing a controlled stream of abrasive over the surface of the material to be marked. Dependent upon the abrasive used, and the settings made, the system can cut or texture VERICODE® Symbols and human-readable markings onto metallic or nonmetallic surfaces. The system operates by directing a mixture of dry air and abrasive material through a small tungsten carbide nozzle at high velocity. Software automatically controls the movement of the

201

marking nozzle, the length of the stop and go pulses, and the speed of flow to produce the requested marking. The system can be adjusted to accurately control the depth of cut. With current technology, the smallest readable symbol produced by the micro-abrasive marking method is 0.375-inch square.

5. Fabric Embroidery—The fabric embroidery marking method involves the use of a computer-driven sewing machine to stitch a representation of the VERICODE® Symbol onto cloth or fabric materials. The marking technique is a simple, cost-effective method for applying durable markings onto cloth and fabric materials. The fabric embroidery marking method could be extremely effective for marking Thermal Protection System (TPS) blankets. Rockwell currently identifies TPS blankets using the ink stamp marking method. The quality of the marking is generally poor due to the coarseness of the fabric and the markings do not hold up well over time. Efforts are now underway to locate heat resistant black thread that can be used in the fabric embroidery marking process. With current technology, the smallest readable symbol produced by the fabric embroidery marking method is 0.50-inch square.

6. Ink Jet—The Jet Equipment Corporation SMS-92-H Standard Marking System can produce high-resolution markings on a wide variety of topographies with no adverse effect on the substrate. This fast, non-contact marking method uses a computer-controlled X/Y/Z marking head to deposit industrial grade ink that dries almost immediately. The ink jet marking method has been approved for use by the aerospace industry. With current technology, the smallest readable symbol produced by the ink jet marking method is 0.125-inch square.
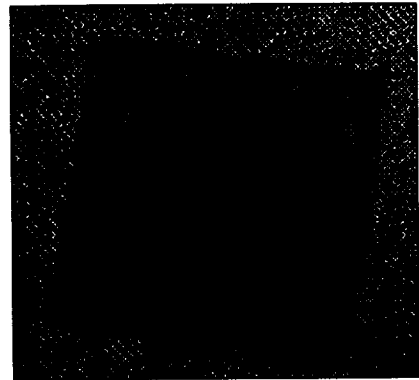

VERICODE® Symbol machine-embroidered on a Thermal Protection System blanket.

Special Coatings

In addition to laboratory tests, there are a number of tests being performed under aerospace production and flight conditions. For instance, there are eight VERICODE® marked TPS tiles being flown on three orbiters in the NASA Space Shuttle fleet (see Figure 1). The TPS tiles are used to protect the orbiters' aluminum skin at launch, in earth orbit, and during the fiery re-entries encountered before landing—one of the most hostile environments an identification mark can encounter. During normal orbiter flight cycles, TPS tiles are subjected to adverse weather conditions on the launch pads, temperature extremes that range from -250 to +2200 degrees Fahrenheit, air flows that can exceed 18,000 miles per hour, and abrasion from dirt and sand during the launch and recovery process. A special thermal coating, Verishield® TM/CTI 43B, designed to withstand extreme variations in temperature on a variety of materials, was developed by Ceram Tech International Ltd., Pomona, New York, to meet TPS requirements. So far, the VERICODE® Symbols have remained readable after multiple Space Shuttle missions.

Phased Implementation

Compressed symbology is being implemented on the turbopump manufacturing process at Rockwell International, Rocketdyne Division, Canoga Park, California. The project activities will include developing compressed symbology-based part identification standards, environmental testing of VERICODE® Symbols marked directly on critical parts and materials, and electronically transferring part information between a shop floor manufacturing environment and a remote computer data base. The Rockwell Huntsville Compressed Symbology Laboratory is testing a portable data capture and transmission system to be used in the field. The device is a small, rugged portable computer linked to a handheld scanner capable of transmitting data to remote host computers via cable or RF transmission (wireless). Also, the Rockwell Huntsville Compressed Symbology Laboratory and Rocketdyne are developing software that interfaces the commercial VeriSystem® to the SSME configuration management systems. Using the VeriSystem® with its direct parts marking capabilities, the automated identification, authentication, and traceability of a part in the manufacturing and assembly process, as well as throughout its life cycle, will be possible.
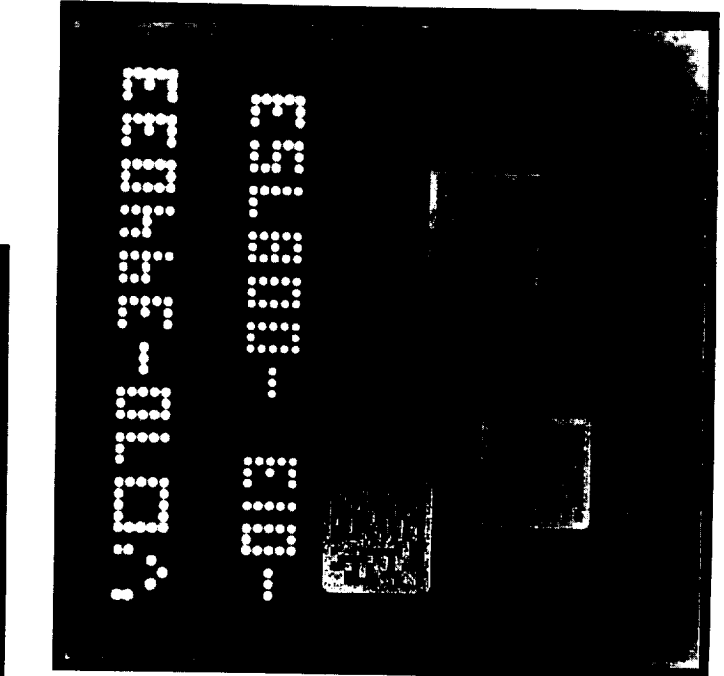
Space Shuttle Discovery

Figure 1: Thermal Protection System tiles marked with VERICODE® Symbols have remained readable after multiple Space Shuttle missions. The symbols were etched into the surface of the tile with a laser and backfilled with a thermal coating called Verishield®

Contingent on test results, the Marshall Space Flight Center Shuttle projects (External Tank, Solid Rocket Booster, and Solid Rocket Motor, etc.) plan the implementation of compressed symbology in current operations where feasible and on all future programs.

Outreach

Compressed Symbology is a dual-use technology that has a wide range of applications in both federal and commercial industries. Because the Rockwell Huntsville Compressed Symbology Laboratory is funded by the government, the technology and experience gained in the lab is available to the public. The Outreach program attempts to transfer technology, gained through tax dollars, into the public and private sectors. Any federal or commercial entity can request assistance on a specific problem by submitting a "Problem Statement" through the Marshall Space Flight Center Technology Utilization Office. Problem statements related to materials marking or compressed symbology are forwarded to the Rockwell Huntsville Compressed Symbology Laboratory where a viable solution is sought. The Rockwell Huntsville Compressed Symbology Laboratory has already responded to Technology Utilization problem statements from all branches of the military, government agencies like NASA, USDA, and FAA, universities, and private industry. In the last sixteen months, the Rockwell Huntsville Compressed Symbology Laboratory has been asked to mark a wide range of materials: from animal carcasses and Jack Daniel's wooden whisky barrels, to small electronics components (resistors, diodes, capacitors) and dental drills.

From ancient cave drawings until 1960, man has kept up with things manually. Yesterday's manual modus operandi was time-consuming, error-prone, and expensive. Today's approach, ushered in by the first practical applications of bar code in 1960, is characterized by bar codes, computers, and paper labels. Bar code is a giant step toward automating yesterday's manual processes, but its technical limitations make it unsuitable for many aerospace, automotive, electronics, and other industrial applications. Tomorrow's approach requires a more advanced API technology. The technology must support direct part marking, data recovery, a higher degree of computerization, and a wide range of "read" orientations and distances. Compressed symbology is the advanced API that NASA and Rockwell International will employ as they reach toward the year 2003 and beyond.