NASA/CR—2015–218215

Marking Tests to Certify Part Identification Processes for Use in Low Earth Orbit

D.L. Roxby
Viking Consulting, Gurley, Alabama

October 2015

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D.L. Roxby
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National Aeronautics and
Space Administration

Marshall Space Flight Center • Huntsville, Alabama 35812

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MARKING TESTS TO CERTIFY PART IDENTIFICATION PROCESSES FOR USE IN LOW EARTH ORBIT

INTRODUCTION

Prior to the Space Shuttle Program, space-borne vehicles were expendable. The marking processes used to identify the parts used in space-borne vehicles were the same ones commonly used to identify parts used in ground operations.

With the advent of reusable space transportation vehicles and retrievable satellites, NASA needed to rethink how part identification markings were applied to their space-borne vehicles. Markings applied to reusable spacecraft needed to survive the extreme environments encountered in space.

International Space Station in Low Earth Orbit

Qualifying marking processes for long-term use in space is especially challenging because this unique environment is difficult to simulate in the laboratory. Consequently, NASA designed a recoverable experiment to subject materials to the harsh environment seen in low Earth orbit (LEO) 50 to 1,240 miles above the Earth's surface. The experiments, positioned on the exterior of the International Space Station, exposed the marked materials to LEO environments. These environmental conditions include, but are not limited to, vacuum, solar ultraviolet (UV) radiation, micrometeoroids and space debris, atomic oxygen (AO), and deep thermal cycles. The experiment was named Materials International Space Station

Experiment (MISSE), and consisted of a suitcase called a Passive Experiment Container (PEC), which contained trays fabricated with inserts to hold material specimens.

Marking experiments were incorporated into four different MISSE packages. These are identified as MISSE 1 and 2, MISSE 3 and 4, MISSE 6, and MISSE 8. The results of these four experiments are consolidated into this final report.

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EXPERIMENT ASSEMBLY

The contractors involved in the MISSE Marking Tests were RVSI, Siemens, Intermec, and Sys-Tec Corporation. These contractors applied Data Matrix™ symbol markings to test coupons made of materials commonly utilized in the construction of the external components used on space transportation vehicles, satellites, and space stations. The materials included aluminum (anodized and painted) used in structural components and glass materials used in windows, mirrors, and lenses. Thermal Protection System (TPS) tile and blankets were not included in the testing program, having been previously tested by an RVSI Researcher on a previous space shuttle marking program.

The markings were applied to test coupons, 0.995-inch-diameter aluminum and glass disks, that were incorporated into material holders. The holders were installed into experiment trays that were subsequently installed into a Passive Experiment Container (PEC). The open PECs are subjected to a thermal vacuum test to insure contamination requirements are met. The PECs were then installed into the PEC Carrier that is subjected to a vibration test. The carriers were then shipped to the Kennedy Space Center (KSC) and installed on a truss in the Space Shuttle Orbiter payload bay. After shuttle launch and rendezvous with the International Space Station (ISS), the PEC was removed from the carrier in the shuttle bay by the astronauts and attached to the exterior of the ISS. An overview of MISSE construction is shown on the next page.

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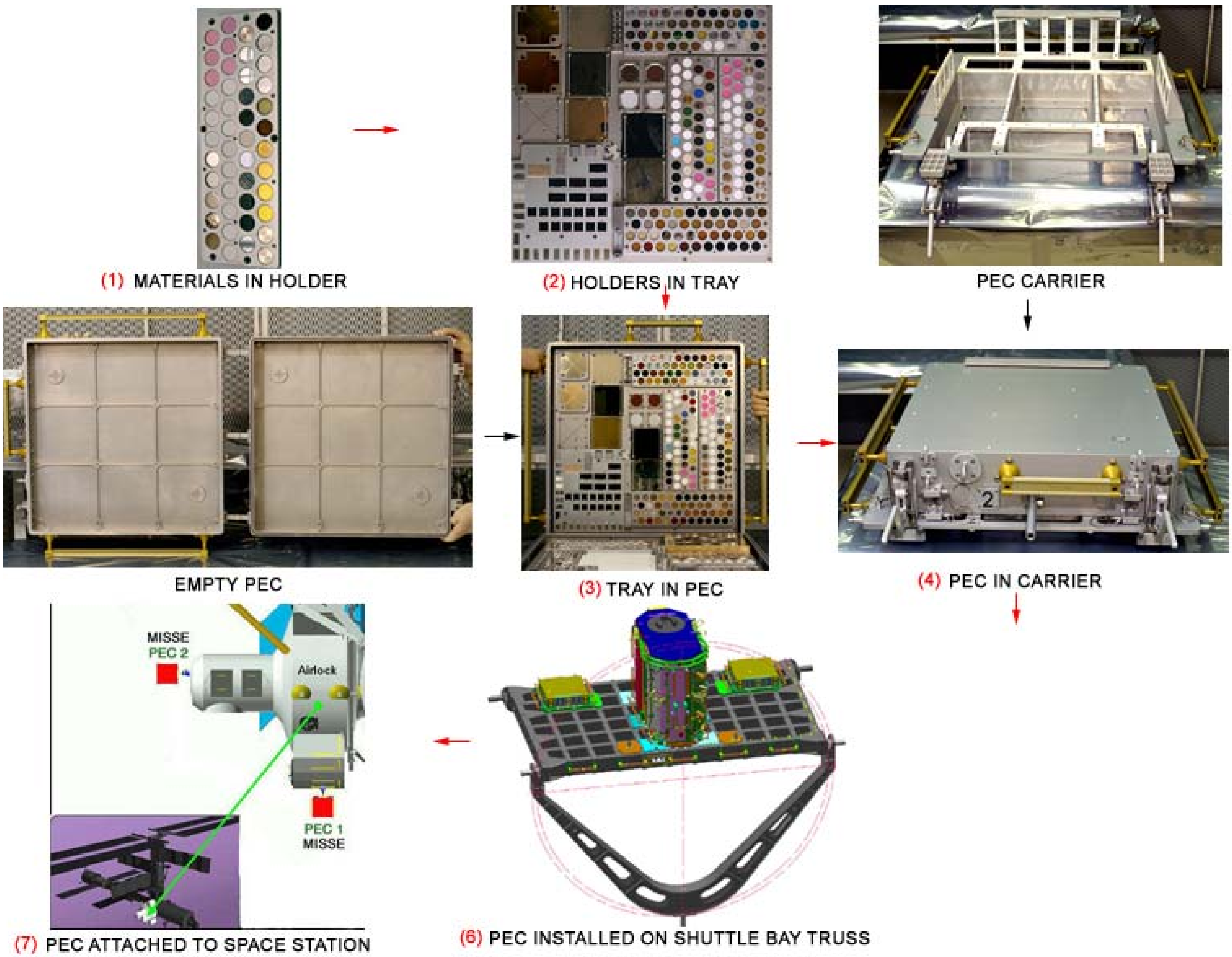
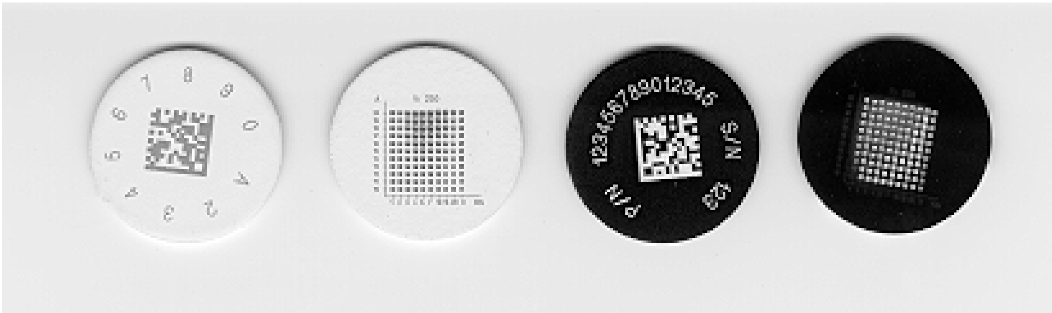
Overview of MISSE Construction



TEST COUPON CONFIGURATIONS

Data Matrix™ Symbols and line pattern test markings were applied to 0.995-inch-diameter aluminum and glass coupons as illustrated below.



Sample 0.995-Inch-Diameter Coupons Created to Test Marking Processes

Tables 1a (Additive Markings) and 1b (Direct Part Markings) define the substrate materials applied to the 0.995-inch disks. They also include the marking category, marking method, marking device, marking media, and protective coatings used in their identification. Technical contacts associated with the marking of each of the disks are also listed.

Table 1a. Part Identification Markings Generated for MISSE 1 Through 8 (Additive Markings).

Marking Category	Marking Method	Marking Device	Marking Media	Substrate Material	Protective Coating	Technical Contacts
Additive Marking	Laser Bonding	Nd:YAG Laser	Cerdec LMM-6000 Metal Coating	Anodized Aluminum	None	Don Roxby, CiMatrix, (256) 830-8123 Andy Axtell, Cerdec, (724) 250-5501 Eva Tang, Rofin-Sinar Laser, (480) 777-1199
	Label Printing	Intermec Printer	Intermec 1 Mil Gloss White Polyester Label with permanent adhesive imaged with TMX3202 Resin Ribbon	Bare Aluminum	None	Glenn Aspenns, Intermec, (513) 874-5882
	Label Printing	Zebra 170X13 Printer	7246 Polyester Label Stock with 350 Adhesive & ITW B324 Resin Ribbon	Bare Aluminum	None	Curt Howard, 3M Converter Markets, 800 786-6597
	Laser Coloring	LabeLase® 1000RUV Desktop Laser-Printing System	Permalabel – Laser Markable Labels attached with 3M Y966 Adhesive	Bare Aluminum	Uncoated and Coated With a Shield Products Clear Coat	Ed O'Neal, InfoSight, (740) 642-3600 Brett Vanhuysen, (734) 854-3000, ext 314
	Laser Engraving	Macsa CO_2 Laser	Tesa Secure 6973 PV3	Bare Aluminum	None	Dave Adams, Tesa Tape, Inc., (704) 553-4686, Don Roxby, Intermec, (256) 776-4349 Michael Sorvino, Datalase (770) 817-4813
	Laser Engraving	LabeLase® 1000RUV Desktop Laser-Printing System	3M 7847 Laser Markable Tape	Bare Aluminum	None	Curt Howard, 3M Converter Markets, 800 786-6597 Brett Vanhuysen, (734) 854-3000, ext 314
	LIVD (Coat & Mark)	Nd:YAG laser	Tin	PPG Glass	None	Don Roxby, Acuity CiMatrix, (256) 830-8123, Eva Tang, Rofin-Sinar Laser, (480) 777-1199 Guy Griffith, PPG, (256) 859-2500 Ext. 2211
	Laser Etch (Coat & Mark)	CO_2 Laser	VAVD - Material Gold	Anodized Aluminum	None	Don Roxby, CiMatrix, (256) 830-8123, Jack L Weeks, VAT (256) 582-5484

Table 1a. Part Identification Markings Generated for MISSE 1 Through 8 (Additive Markings) (Continued).

Marking Category	Marking Method	Marking Device	Marking Media	Substrate Material	Protective Coating	Technical Contacts
Additive Markings	Laser Etch (Coat & Mark)	LVO4 Laser	VAVD - Material Gold	Anodized Aluminum	None	Don Roxby CiMatrix, (256) 830-8123, Jennifer Bunis, Synrad, (800) 796-7231 Jack L Weeks, VAT, (256) 582-5484
	Laser Etch (Coat & Mark)	Nd:YAG Laser	VAVD - Material Gold	Anodized Aluminum	None	Don Roxby, CiMatrix, (256) 830-8123 Jack L Weeks, VAT, (256) 582-5484
	Laser Etch (Coat & Mark)	Nd:YAG Laser	VAVD - Material Gold	AZ93 Coating	None	Don Roxby, CiMatrix, (256) 830-8123 Jack L Weeks, VAT, (256) 582-5484
	Laser Coloring (Coat & Mark)	CO_2 Laser	Datalase Paint	Anodized Aluminum	Shield Products Clear Coat	Michael Sorvino, Datalase, (770) 817-4813 Don Roxby, Intermec, (256) 776-4349 Robert Diefendorf, Shield Products, Inc., (904) 880-6060
	Laser Coloring (Coat & Mark)	40 Watt Universal Laser	InfoSight High Temperature Paint	Anodized Aluminum	Shield Products Clear Coat	Ed O'Neal, InfoSight, (740) 642-3600, Brett Vanhuysen, (734) 854-3000, Ext 314 Robert Diefendorf, Shield Products, Inc., (904) 880-6060
	Laser Coloring (Coat & Mark)	10 Watt Paragon Fiber Laser	Ferro Paint	Anodized Aluminum	Shield Products Clear Coat	Joe Sarver, Ferro, 724-223-5965 Robert Diefendorf, Shield Products, Inc., (904) 880-6060

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Table 1b. Part Identification Markings Generated for MISSE 1 Through 8 (Direct Part Markings).

Part ID Category	Marking Method	Marking Device	Marking Media	Substrate Material	Protective Coating	Technical Contacts
Direct Part Marking	Laser Etch	Nd:YAG Laser	VAVD - Material Gold	Corning Glass	None	Don Roxby, CiMatrix, (256) 830-8123, Jack L Weeks, VAT, (256) 582-5484 Guy Griffith, PPG, (256) 859-2500 Ext. 2211
	Dot Peen	Dot Peen Marker	Dot Peen	Bare Aluminum	None	Don Roxby, CiMatrix, (256) 830-8123 Richard Pentz, DAPRA, (800) 442-6275
	Laser Shot Peen	High-Average-Power Nd: Glass Laser	None	Bare Aluminum	None	L. A. Hackel, Lawrence Livermore National Laboratory Don Roxby, CiMatrix, (256) 830-8123
	Laser Etch	Nd:YAG Laser	None	Bare Aluminum	None	Don Roxby, CiMatrix, (256) 830-8123 Eva Tang, Rofin-Sinar Laser, (480) 777-1199
	Electro-Chem Etch	Standard Pwr. Unit	Electrolyte	Bare Aluminum	None	Don Roxby, CiMatrix, (256) 830-8123 Sy Haeri, Electro-Chem Etch Metal Marking, Inc., (714) 671-7744
	Gas Assisted Laser Etch (GALE)	LVO4 Laser	Marking Gas - Nitrogen	Bare Aluminum	None	Don Roxby, CiMatrix, (256) 830-8123, Mary Helen McCay, University of Tennessee Space Institute (UTSI), (931) 393-7473 Mark Villand, LMT, (303) 664-9000 ext 624
	Laser Induced Surface Improvement (LISI)	Nd:YAG Laser	University of Tennessee – Proprietary Mixture	Bare Aluminum	None	Don Roxby, CiMatrix, (256) 830-8123, Mary Helen McCay, University of Tennessee Space Institute (UTSI), (931) 393-7473 Eva Tang, Rofin-Sinar Laser, (480) 777-1199

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PRE-FLIGHT AND POST-FLIGHT MARK GRADING

Prior to flight, each marked coupon was photographed under magnification. These photographs were stored to compare against the samples after being exposed to the LEO environments.

All of the Data Matrix™ symbols flown were graded as defined by MIL-STD-130, which provides acceptance criteria for all marking procedures that can be used at the Supplier's choice: ISO/IEC 15415, AIM DPM-1-2006 or SAE AS9132. The marked samples flown on MISSE 1 and 2, MISSE 3 and 4, and MISSE 6 were graded using AIM DPM-1-2006. The marked sample flown on MISSE 8 was graded using ISO/IEC 15415. These specifications require an A or B grade at point of manufacture and remarking in the field after the mark quality verification grade falls to a C.

The Data Matrix™ symbols flown on MISSE 1 and 2 were read and graded using an RVSI HawkEye 1500 Series Smart Camera Reader with built-in Direct Part Mark Quality Verification Software. The markings flown on MISSE 3 and 4 were graded using a Microscan Quadrus® Verifier and the markings flown on MISSE 6 were graded using a WebScan TruCheck 401. The MISSE 8 markings were graded using a Cognex Dataman. All the markings scored a B or better as shown in Tables 2, 4, 6, and 8.

MISSE 1 AND 2 MARKING EXPERIMENTS

The first marking specimens were incorporated into MISSE 1 and 2 (one year orbital experiments) and consisted of NASA approved marking processes and a number of newly developed laser additive marking techniques deemed safe for use in safety critical applications. The experiment contained Data Matrix™ symbols applied using Laser Bonding, Vacuum Arc Vapor Deposition, Gas Assisted Laser Etch, and Chemical Etch.

MISSE 1 and 2 were launched into low Earth orbit aboard Space Shuttle Discovery (NASA orbiter vehicle (OV) designation 103) during Shuttle Transportation System (STS) mission 105 on August 10, 2001. The experiment packages were attached to the exterior of the International Space Station (ISS) by Astronaut Patrick G. Forrester during a space walk conducted on August 16, 2001.

STS-105 (Discovery) Launch on August 10, 2001

MISSE 2 Positioned on Exterior of the International Space Station by Mission Specialist Patrick G. Forrester on August 16, 2001

PEC-1 was positioned on the lower portion of the ISS Airlock so that it would be exposed to the maximum amount of UV radiation and AO. PEC-2 was positioned on the side of the ISS Airlock to receive UV radiation, but a minimal amount of exposure to atomic oxidation.

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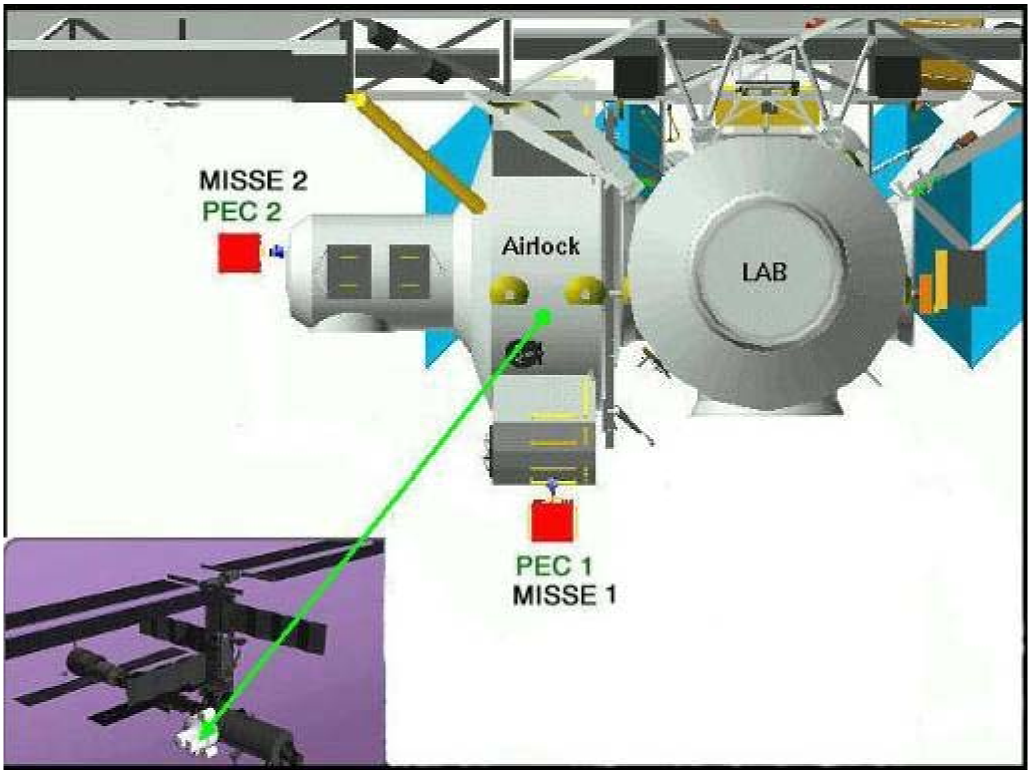


Illustration of PEC Locations on the Exterior of the ISS

Shuttle Astronauts visited the MISSE 1 and 2 experiments to make observations and to take photographs while they were in orbit. These Extra Vehicular Activities (EVAs) were made to the experiments in September, October, and December of 2001, February, April, and October of 2002 and March, April, and August of 2003. The part identification markings included in the MISSE experiments were clearly visible in many of the photographs and appeared to be readable.

MISSE 1 Samples

August 2003 EVA

As a result of the Columbia incident, retrieval of the MISSE 1 and 2 experiments, originally planned for one year in orbit, was delayed until the second mission following return to flight. Both of these experiments were recovered early during the STS-114 mission. Astronaut Stephen Robinson retrieved MISSE 1 and 2 on July 30, 2005 when an opportunity presented itself during his record-breaking 6 hour, 50 minute space walk. The experiments were subjected to a total 1443 days of LEO exposure, or just 17 days short of four years.

MISSE 1 and 2 were retrieved and returned to Earth on August 10, 2005. As a result of bad weather (low cloud cover) at the KSC, Discovery was forced to make a night landing at the Dryden Flight Research Center (DFRC), Edwards Air Force Base (EAFB) California. The Discovery touched down on Runway 22 at 5:11 a.m. (8:11 ET) and was towed to the Mate/Demate facility where technicians performed inspections, drained and purged the fuel systems, and loaded the orbiter onto NASA's modified 747 carrier aircraft for the return flight to KSC.

Discovery Lands at EAFB at End of the STS-114 Mission

Discovery arrived at KSC on August 20, 2005 and was towed from the Shuttle Landing Facility to the Orbiter Processing Facility (OPF) on August 22, 2005. The payload bay doors were opened to offload the materials brought back from the International Space Station on August 23, 2005. MISSE 1 and 2 were then packaged and returned to the Atmospheric Systems Development Laboratory at NASA's Langley Research Center (LARC), Hampton, Virginia, where the PECs were inspected, disassembled, and photographed. The marked coupons were then hand carried back to the RVSI Symbology Research Center, Huntsville, Alabama, where mark quality was analyzed and decoding tests were conducted to qualify identification processes for future retrievable spacecraft and satellites.

PECs Prior to Disassembly

Data from this in-orbit experiment has been added to NASA-STD-6002 Revision C, "Applying Data Matrix™ Identification Symbols on Aerospace Parts," and NASA-HDBK-6003 Revision B, "Application of Data Matrix™ Identification Symbols to Aerospace Parts Using Direct Part Marking Methods/Techniques." The standard updates were provided to the USAF for possible inclusion into MIL-STD-130**, "**Identification Marking of U.S. Military Property."

Marking Processes Tested on MISSE 1 and 2

Five different marking processes were incorporated into the MISSE 1 and 2 experiments. These included Electro-Chemical Coloring, Laser Bonding, Vacuum Arc Vapor Deposition (VAVD) coatings, Gas Assisted Laser Etch (GALE), Laser Engraving used in conjunction with and Laser Inducted Vapor Deposition (LIVD), and Gas Assisted Laser Etch (GALE.) These processes are explained as follows:

Electro-Chemical Coloring – Electro-chemical coloring marks are produced using an electro-chemical process used in conjunction with a stencil. In this process, metal is removed and replaced using an alternating current (AC) passed through a chemical that oxidizes (discolors) the metal. No pigments are added in this process. The penetration of coloration into the metal is controlled by the amplitude and frequency of the AC potential. The resulting color is determined by the chemical properties of the metal and the electrolyte (salt solution) used.

Laser Bonding – Laser bonding is an additive process that involves the bonding of a material to the substrate surface using the heat generated by an Nd:YAG, YVO4, or carbon dioxide (CO_2) laser. The materials used in this process are commercially available, and generally consist of a glass-frit powder or ground metal oxides mixed with inorganic pigment, and a liquid carrier (usually water or mineral oil). The pigment can be painted or sprayed onto the surface to be marked, or transferred via pad printer, screen printer, or coating roller. Adhesive-backed tapes coated with an additive are also used in this process. Laser bonding can also be performed using a CO_2 laser and ink foils for less harsh environments. This is accomplished using heat levels that have no noticeable effect on metal or glass substrates and that are safe for use in safety-critical applications. The markings produced using this technique are resistant to high heat, unaffected by salt fog/spray, and are extremely durable, dependent on the material used.

Vacuum Arc Vapor Deposition (VAVD) – Laser engraving is acceptable in safety-critical applications when used in conjunction with a "coat and remove" process. This process involves the coating of a part with a medium of contrasting color that is subsequently removed by the laser to expose the underlying material. The coatings used in the MISSE 1 and 2 experiments were applied using a new Vacuum Arc Vapor Deposition (VAVD) process developed by Siemens and Vacuum Arc Technologies (VAT) under a Space Act Agreement with the Marshal Space Flight Center (MSFC). In this process, a thin film is produced by injecting a small amount of inert gas, such as argon, into the chamber to serve as the ionization medium that allows an arc to be sustained in the vacuum environment. After the flow of gas is released, a high current, low voltage arc is produced between the slightly separated coating material and an electrode to create a jet of fully ionized metal vapor plasma at minute hot spots on the charge. The resulting plasma is accelerated onto the item to be marked to form an amorphous film that can range in thickness from angstroms to several thousandths of an inch, depending upon the length of firing time.

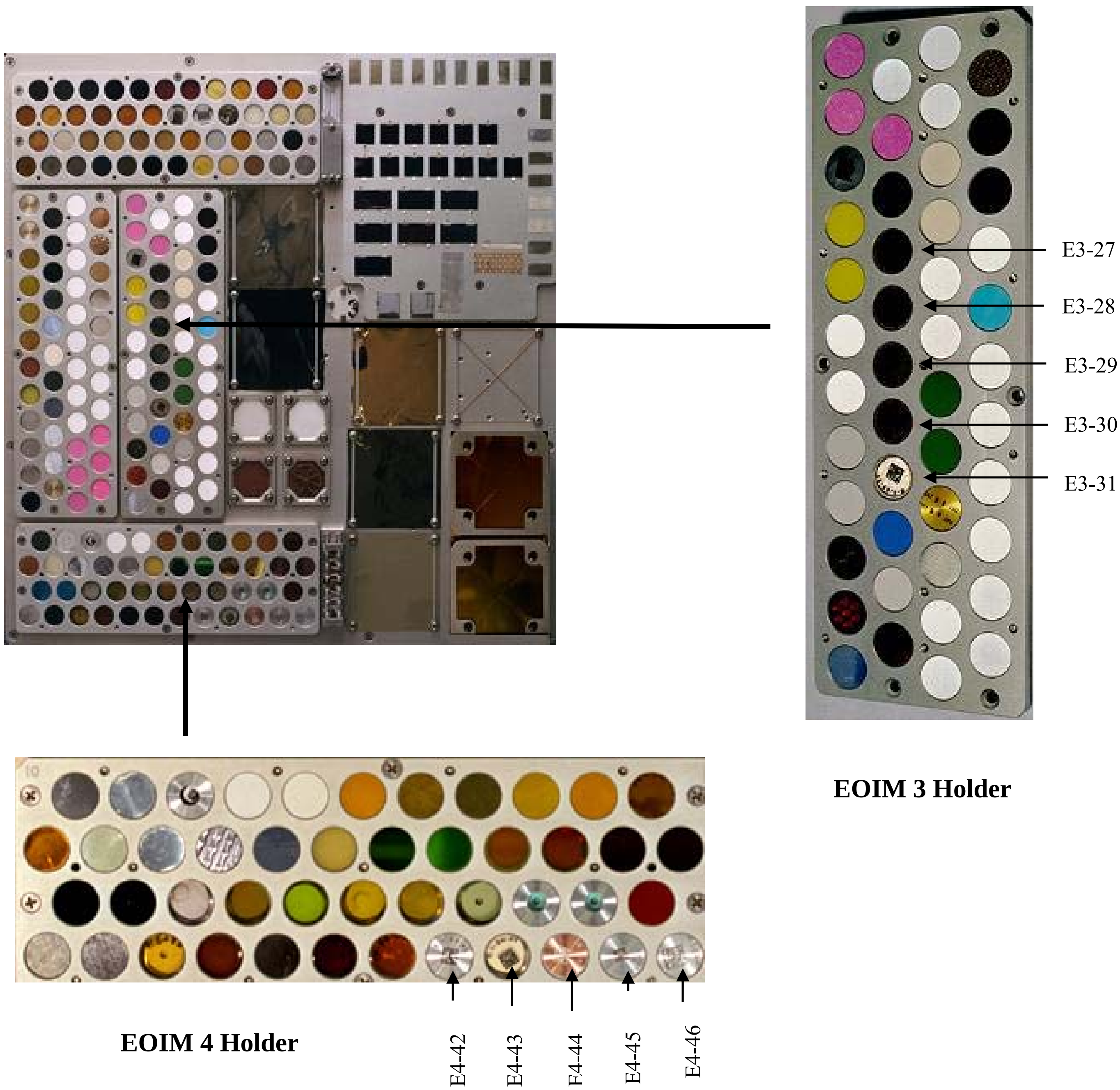
Laser Inducted Vapor Deposition (LIVD) – The LIVD process, developed by RVSI, is used to apply part identification markings, heating and defrosting strips, antennas, circuitry, and Sun shields to transparent materials. This is accomplished by vaporizing material from a marking media trapped under a transparent part using heat generated from a visible spectrum laser. The gaseous vapors and droplets resulting from the heat buildup condense on the cooler transparent surface to form a hard uniform coating that is applied in a prescribed pattern. The process is accomplished under normal office conditions without the need for high heat or sealed gas/vacuum chambers.

Gas Assisted Laser Etch (GALE) - Laser marking made in ambient environments often results in limited contrast between the engraved mark and the background on which it is placed and the number of different materials that can be marked. The GALE technique is used to mark an object in the presence of a selected gaseous environment, enhancing contrast and increasing readability. The mark is made using low-power settings, enabling it to be made with minimal laser interaction with the target material. GALE accomplishes this by the use of an assist gas that reacts with the material under the influence of the laser energy to produce a reactant that is a different reflective color from the background. The assist gases might be reducing, oxidizing, or even inert, their selection being dependent upon the target material. A contrasting surface results at the coincident point of the laser, gas, and material, producing a high-contrast, readable mark created in a controlled environment. Tests performed at the University of Tennessee Space Institute have demonstrated that the process should be safe for use in most aerospace marking applications.

TEST COUPON POSITIONING ON THE MISSE 1 AND 2 EXPERIMENT TRAYS

The marked disks selected for MISSE 1 AND 2 were installed onto Experiment Holders (trays) EOIM 3 and EOIM 4 on the top side of the Atomic Oxygen (AO) and Solar Tray 1, MISSE 1, PEC 1 and onto Experiment Holders EOIM 10 and D2 on the top side of the Ultra Violet (UV) Tray 2, MISSE 2, PEC 2.

MISSE 1, Tray 1, Top



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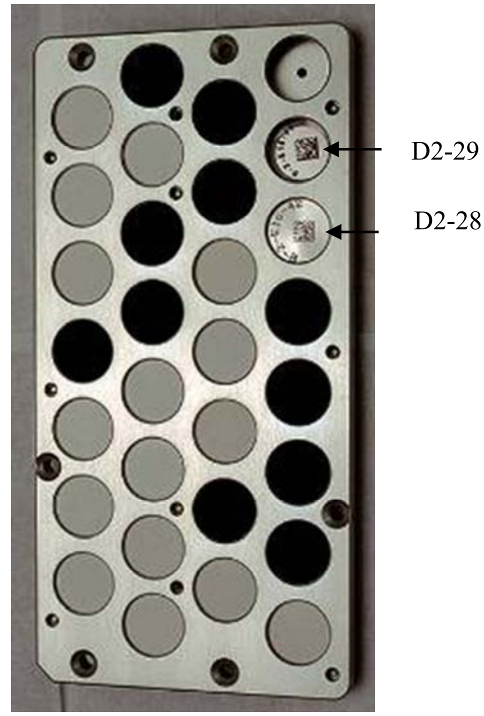
MISSE 2, Tray 2, Top



D2 Holder

EOIM 10 Holder (Flipped Horizontally)

Table 2. MISSE 1 and 2 Pre-Flight Marking Grades.

Specimen Number	Base Material	Marking Method	Marking Material	Encoded Info.	Planned Orbit Duration	Color of Mark	Pre-Flight Grade	Marking Equipment
B-1-E3-27	Glass	LIVD	Brass	Line Pattern	1 yr.	Dark Brown	Good Contrast	Rofin-Sinar Nd:YAG Laser
B-1-E3-28	Glass	LIVD	Tin	Line Pattern	1 yr.	Black	Good Contrast	Rofin-Sinar Nd:YAG Laser
B-1-E3-29	Glass	Laser Bonding	Cerdec RD-6005	Line Pattern	1 yr.	Gray-Black	Excellent Contrast	Rofin-Sinar Nd:YAG Laser
B-1-E3-30	Glass	VAVD	Copper	Line Pattern	1 yr.	Dark Gray	Good Contrast	Rofin-Sinar Nd:YAG Laser
B-1-E3-31	Glass	LIVD	Tin	B1E331	1 yr.	Black	A	Rofin-Sinar Nd:YAG Laser
B-1-E4-42	Aluminum	Laser Bonding	Cerdec RD-6000	B1E442	1 yr.	Black	A	Rofin-Sinar Nd:YAG Laser
B-1-E4-43	Glass	Laser Bonding	Cercec RD-6005	B1E443	1 yr.	Black	A	Rofin-Sinar Nd:YAG Laser
B-1-E4-44	Aluminum	VAVD	Copper	B1E444	1 yr.	White	A	Rofin-Sinar Nd:YAG Laser
B-1-E4-45	Aluminum	GALE	Argon Gas	CiMatx	1 yr.	Dark Gray	A	LMT Diode-Pumped Laser
B-1-E4-46	Aluminum	Chemical Etching	SCE-4	B1E446	1 yr.	Gray	A	Electo-Chem Etch Machine
B-1-E10-03	Glass	LIVD	Brass	Line Pattern	1 yr.	Gray-Black	Excellent Contrast	Rofin-Sinar Nd:YAG Laser
B-1-E10-04	Glass	LIVD	Tin	Line Pattern	1 yr.	Black	Good Contrast	Rofin-Sinar Nd:YAG Laser
B-1-E10-05	Glass	Laser Bonding	Cerdec RD-6005	Line Pattern	1 yr.	Gray-Black	Excellent Contrast	Rofin-Sinar Nd:YAG Laser
B-1-E10-06	Glass	VAVD	Copper	Line Pattern	1 yr.	Dark Gray	Good Contrast	Rofin-Sinar Nd:YAG Laser

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Table 3. MISSE 1 and 2 Pre-Flight/Post-Flight Marking Comparison.

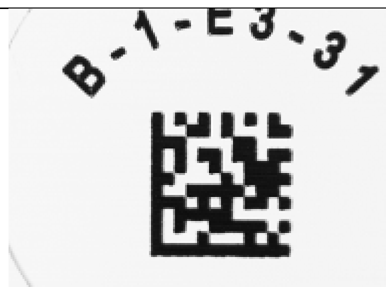
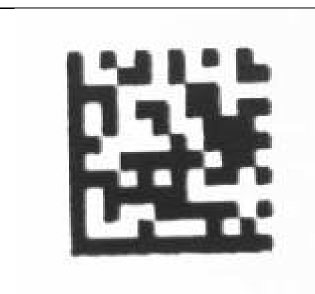
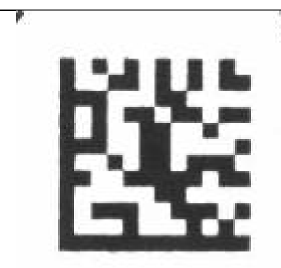
Sample Number	Marking Comparison			
	Pre-Flight Mark Photograph	**Pre-Flight Verification Grade**	**Post-Flight Mark Photograph**	**Post-Flight Verification Grade**
B-1-E3-27 LIVD - Brass	Line Pattern	Good Contrast – Excellent Line Resolution	Sample being Evaluated by Boeing Phantom Works	N/A
B-1-E3-28 LIVD - Tin	Line Pattern	Good Contrast – Excellent Line Resolution	Sample being Evaluated by Boeing Phantom Works	N/A
B-1-E3-29 Laser Bonding	Line Pattern	Good Contrast – Excellent Line Resolution	Sample being Evaluated by Boeing Phantom Works	N/A
B-1-E3-30 VAVD - Copper	Line Pattern	Good Contrast – Excellent Line Resolution	Sample being Evaluated by Boeing Phantom Works	N/A
B-1-E3-31 LIVD - Tin		% Contrast A Axial Uniformity A Print Growth A Error Correction A Overall Grade A		% Contrast A Axial Uniformity A Print Growth A Error Correction A Overall Grade A
B-1-E4-42 Laser Bonding		% Contrast A Axial Uniformity A Print Growth A Error Correction A Overall Grade A		% Contrast A Axial Uniformity A Print Growth A Error Correction A Overall Grade A

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Table 3. MISSE 1 and 2 Pre-Flight/Post-Flight Marking Comparison (Continued).

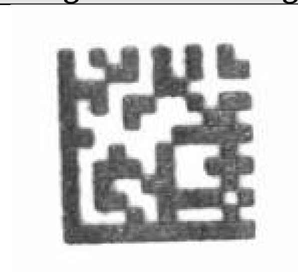
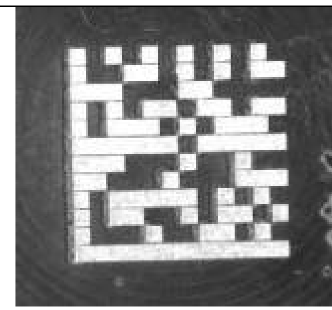
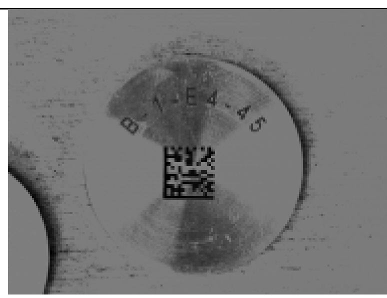
Sample Number	Marking Comparison			
	Pre-Flight Mark Photograph	**Pre-Flight Verification Grade**	**Post-Flight Mark Photograph**	**Post-Flight Verification Grade**
B-1-E4-43 Laser Bonding		% Contrast A Axial Uniformity A Print Growth A Error Correction A Overall Grade A		% Contrast B Axial Uniformity A Print Growth Error Correction A Overall Grade B
B-1-E4-44 Laser Coat & Remove - VAVD		% Contrast A Axial Uniformity A Print Growth A Error Correction A Overall Grade A		% Contrast A Axial Uniformity A Print Growth A Error Correction A Overall Grade A
B-1-E4-45 GALE		% Contrast A Axial Uniformity A Print Growth A Error Correction A Overall Grade A		% Contrast A Axial Uniformity A Print Growth A Error Correction A Overall Grade A

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Table 3. MISSE 1 and 2 Pre-Flight/Post-Flight Marking Comparison (Continued).

Sample Number	Marking Comparison			
	Pre-Flight Mark Photograph	**Pre-Flight Verification Grade**	**Post-Flight Mark Photograph**	**Post-Flight Verification Grade**
B-1-E10-03 LIVD - Brass	Line Pattern	Good Contrast – Excellent Line Resolution	Sample being Evaluated by Boeing Phantom Works	N/A
B-1-E10-04 LIVD - Tin	Line Pattern	Good Contrast - Excellent Line Resolution	Sample being Evaluated by Boeing Phantom Works	N/A
B-1-E10-05 Laser Bonding	Line Pattern	Excellent Contrast And Line Resolution	Sample being Evaluated by Boeing Phantom Works	N/A
B-1-E10-06 VAVD - Copper	Line Pattern	Good Contrast – Excellent Line Resolution	Sample being Evaluated by Boeing Phantom Works	N/A

The results of MISSE 1 and 2 were compiled in a Siemens Report dated October 11, 2005. Data from this report have been extracted and included in this document.

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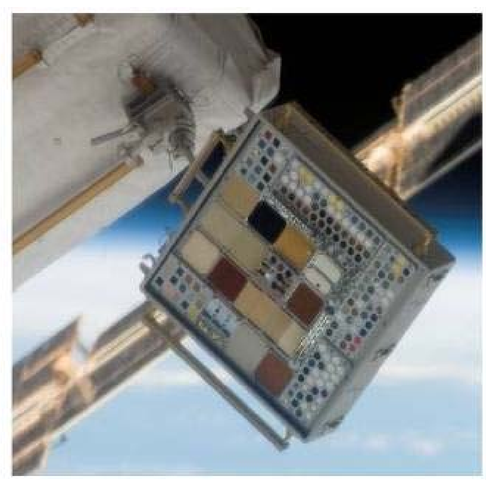
MARKING EXPERIMENTS TESTED ON MISSE 3 AND 4

MISSE 3 and 4 included more robust marking processes than those flown on MISSE 1 and 2. The experiment flown on MISSE 3 and 4 included Data Matrix™ symbols applied using Mechanical Dot Peening, Laser Etching, and Laser Induced Surface Improvement and Laser Shot Peening.

MISSE 3 and 4 were launched by Space Shuttle Orbiter Discovery during mission STS-121 on August 3, 2006. Astronauts Piers Sellers and Michael E. Fossum attached the experiments to the exterior of the International Space Station on August 3, 2006. MISSE 3 went on one of the high-pressure tanks around the crew lock, while MISSE 4 was installed on Quest's Joint Airlock. The *Quest* Joint Airlock, previously known as the Joint Airlock Module, is the primary airlock for the International Space Station. *Quest* was designed to host spacewalks with both Extravehicular Mobility Unit (EMU) spacesuits and Orlan space suits.

Shuttle Astronauts took photographs of MISSE 3 and 4 after deployment and revisited the experiments to take additional photographs in December 2006 to assess their condition.



This image of the MISSE 3 PEC was taken on December 18, 2006. At this point, MISSE 3 has been exposed to the space environment for approximately four months.

Astronaut Mission Specialists Rick Mastracchio and Dafydd "Dave" Williams retrieved MISSE 3 and 4 during mission STS-118, the 22nd flight to the International Space Station. The experiments were returned from orbit on August 8, 2007 aboard space shuttle Endeavour (NASA orbiter vehicle designation OV-105). Orbiter Endeavour's main gear touched down on KSC Runway 15 at 12:32:16 p.m. Nose gear touchdown was at 12:32:29 pm and wheel stop was at 12:33:20 pm. Endeavour was towed to the OPF the same day.

Image to right: Endeavour is maneuvered into the Orbiter Processing Facility at NASA's KSC in Florida after its return to Earth on Aug. 21, 2007. While in the OPF, MISSE 3 and 4 were removed and prepared for transportation to the Atmospheric Systems Development Laboratory at NASA's Langley Research Center (LARC), Hampton, Virginia.

Endeavour Towed Into the OPF

The marked samples were removed from their trays and hand-carried back to the MSFC, Huntsville, Alabama, where they were photographed and inspected prior to delivery to Intermec Technologies for mark quality verification testing. This activity was successfully completed on October 11, 2007.

Marking Processes Tested on MISSE 3 and 4

Four different, more robust marking processes were incorporated into MISSE 3 and 4. These included Mechanical Dot Peening, Laser Etching, Laser Induced Surface Improvement (LISI™), and Laser Shot Peen. These processes are described below:

Mechanical Dot Peen – Mechanical dot peening, a stamp impression method, is achieved by striking a carbide or diamond-tipped marker stylus against the surface of the material being marked. Symbol size is controlled by the size and tip angle of the stylus, dot spacing, or by altering the number of strikes per data cell. Single strikes are used to create small symbols. Multiple strikes per data cell may be used to create larger symbols. The force needed varies with the hardness level of the material being marked.

Laser Etching – Laser etching is a process used to apply heat to the surface of the material being marked using a visible wavelength laser. The etching process is caused when the heat level exceeds the melting point of the substrate being marked. The advantage of using this technique instead of laser coloring on metal is increased marking speed. Excellent results can be routinely obtained at penetration depths of less than 0.001 in. (0.025 mm). This technique, however, should not be used on some metals in safety-critical parts because cracks produced in the molten metal during cooling can propagate into the underlying substrate. These cracks can expand downward when stressed or during temperature cycles that cause expansion and contraction. Laser etched parts subjected to these conditions can fail in use.

Laser Induced Surface Improvement (LISI™) – LISI™ is similar to laser bonding except that the additive material is melted into the metallic host substrate to form an improved alloy with high-corrosion resistance and wear properties. LISI™ is generally used as a surface coating, but can be applied directly to parts to form a symbol. Where needed, a LISI™ patch can be applied that is subsequently marked using another intrusive or non-intrusive marking method.

Laser Shot Peen – Laser shot peen marking is a process for metal components that imprints an identification coding into the surface and leaves the surface in residual compressive stress. The technique involves the use of a laser-peening system that impresses an image in the near field spatial profile of the laser beam onto the metal in the form of a relief pattern. The creation of a compressive stress is highly advantageous for safety-critical parts since it leaves the component resistant to fatigue failure and stress-corrosion cracking. In the laser-peening process, a thin layer of absorptive material is placed over the area to be peened, and a thin, approximately 1-mm-thick layer of fluid is flowed over the absorption layer. A high-intensity laser with fluence of approximately 100 J/cm^2 and pulse duration of 15 ns illuminates and ablates material from the absorption layer, creating an intense pressure pulse initially confined by the water layer. This pressure creates a shockwave that strains the metal surface in a two-dimensional pattern directly correlated to the laser-intensity profile at the metal surface. By creating a desired pattern upstream in the light field and imaging it onto the metal surface, the entire desired pattern can be pressure-printed with a single laser pulse. By employing spatial light modulation of the near-field beam and subsequent imaging of this pattern onto the metal, a new Data Matrix™ can be created with each laser pulse.

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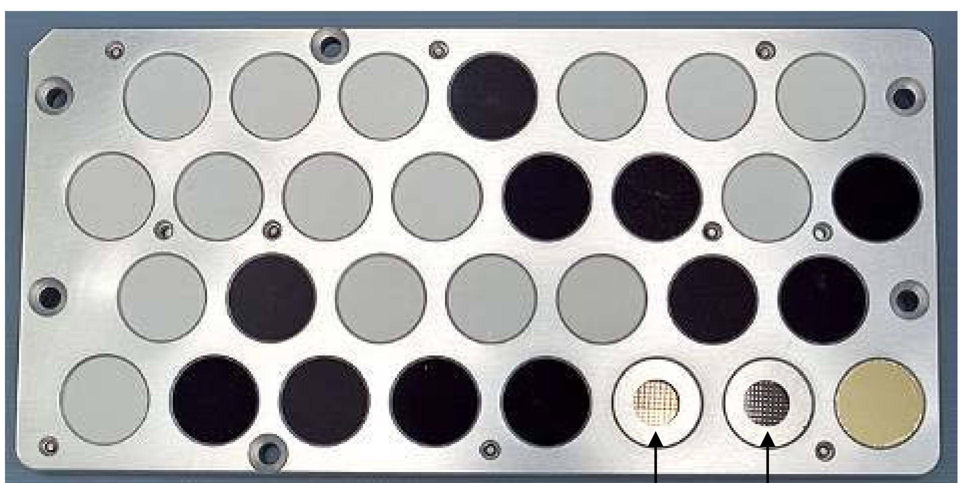
TEST COUPON POSITIONING ON THE MISSE 3 AND 4 EXPERIMENT TRAYS

MISSE 3, Tray 1, Top

D4 Holder



D4-28 D4-29

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MISSE 4, Tray 1, Top

E16 Holder

2-E16-42

2-E16-43

2-E16-44

2-E16-45

2-E16-46

MISSE 4, Tray 2, Top

B9 Holder

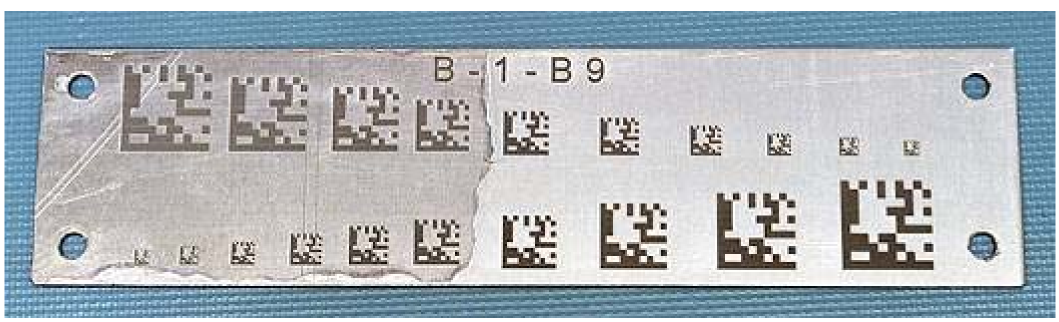

Table 4. MISSE 3 and 4 Pre-Flight Marking Grades.

Specimen Number	Base Material	Marking Method	Marking Material	Encoded Info.	Planned Orbit Duration	Color of Mark	Pre-Flight Grade	Marking Equipment
B-1-B9	Aluminum Plate	Laser Etching	N/A	123456	3 yrs.	Gray	A	Rofin-Sinar Nd:YAG Laser
B-2-E16-42	Aluminum	Dot Peen	N/A	2E1642	3 yrs.	White	A	Telesis TMP 6000 Pinstamp
B-2-E16-43	Aluminum	Laser Etching	N/A	2E1643	3 yrs.	Dark Gray	A	Rofin-Sinar Nd:YAG Laser
B-2-E16-44	Aluminum	LISI	Metallic Powders	2E1644	3 yrs.	Dark Gray	A	Rofin-Sinar Nd:YAG Laser
B-2-E16-45	Aluminum	Laser Shot Peening	N/A	2E1645	3 yrs.	White	B	Neodymium-Doped glass laser
B-2-E16-46	7980 Glass (Corning)	LIVD	Tin	2E1646	3 yrs.	Black	A	Rofin-Sinar Nd:YAG Laser
1-D4-28	Glass	VAVD	Copper	Line Pattern	3 yrs.	Dark brown	Excellent Contrast	Rofin-Sinar Nd:YAG Laser
1-D4-29	Glass	VAVD	Copper	Line Pattern	3 yrs.	Light Brown	Good Contrast	Rofin-Sinar Nd:YAG Laser
1-D6-28	Glass	LIVD	Brass	B1E107	3 yrs.	Dark Brown	A	Rofin-Sinar Nd:YAG Laser

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Table 5. MISSE 3 and 4 Pre-Flight and Post-Flight Comparison.

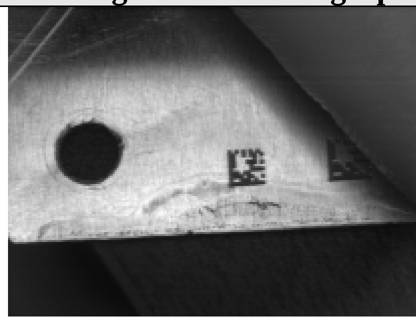
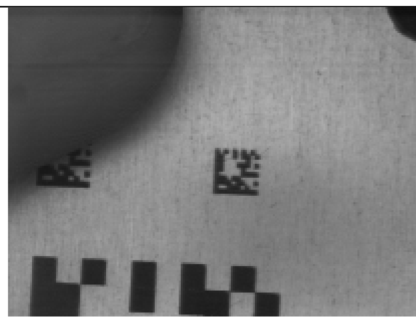
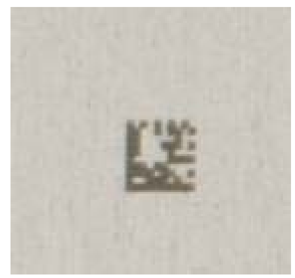
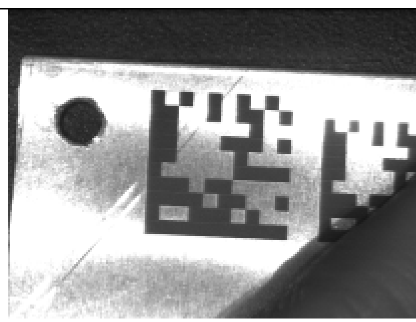
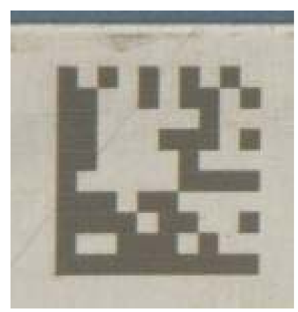
Sample Number	Marking Comparison			
	Pre-Flight Mark Photograph	Pre-Flight Verification Grade	Post-Flight Mark Photograph	Post-Flight Verification Grade
B-1-B9 Small - Bare Laser Etch Data Cell Size Study		% Contrast A Axial Uniformity A Print Growth A Error Correction A Overall Grade A		% Contrast A Axial Uniformity A Print Growth A Error Correction A Overall Grade A
B-1-B9 Small - Anodized Laser Etch Data Cell Size Study		% Contrast A Axial Uniformity A Print Growth A Error Correction A Overall Grade A		% Contrast A Axial Uniformity A Print Growth A Error Correction A Overall Grade A
B-9-B9 Large - Laser Etch Data Cell Size Study		% Contrast A Axial Uniformity A Print Growth A Error Correction A Overall Grade A		% Contrast A Axial Uniformity A Print Growth A Error Correction A Overall Grade A

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Table 5. MISSE 3 and 4 Pre-Flight and Post-Flight Comparison (Continued).

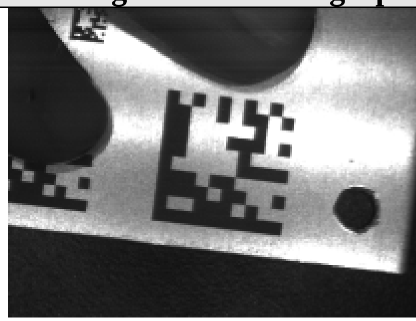
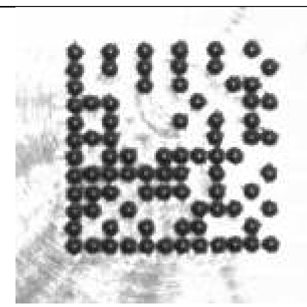
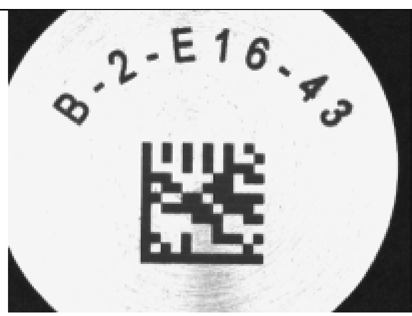
Sample Number	Marking Comparison			
	Pre-Flight Mark Photograph	Pre-Flight Verification Grade	Post-Flight Mark Photograph	Post-Flight Verification Grade
B-1-B9 Large - Anodized Laser Etch Data Cell Size Study		% Contrast A Axial Uniformity A Print Growth A Error Correction A Overall Grade A		% Contrast A Axial Uniformity A Print Growth A Error Correction A Overall Grade A
B-2-E16-42 Dot Peen		% Contrast A Axial Uniformity A Print Growth A Error Correction A Overall Grade A		% Contrast A Axial Uniformity A Print Growth A Error Correction A Overall Grade A
B-2-E16-43 Laser Etch		% Contrast A Axial Uniformity A Print Growth A Error Correction A Overall Grade A		% Contrast A Axial Uniformity A Print Growth A Error Correction A Overall Grade A

Table 5. MISSE 3 and 4 Pre-Flight and Post-Flight Comparison (Continued).

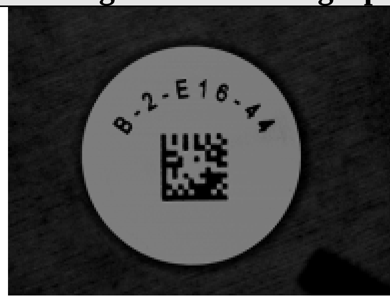
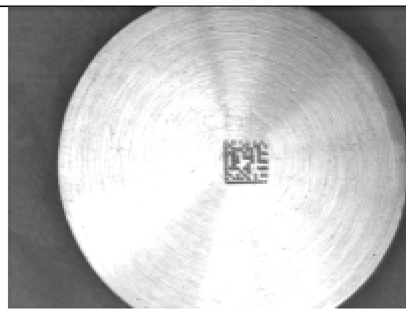
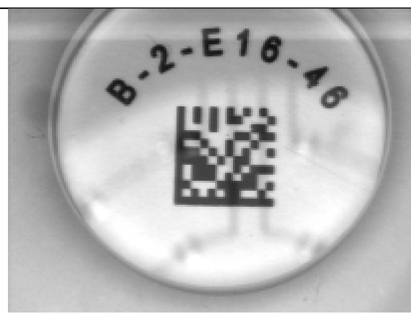
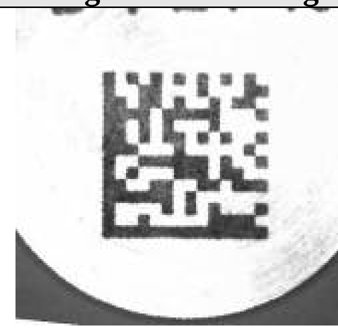
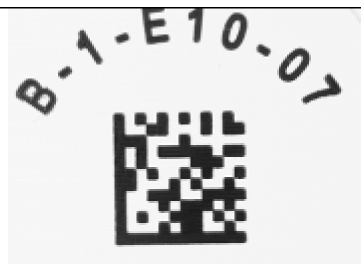
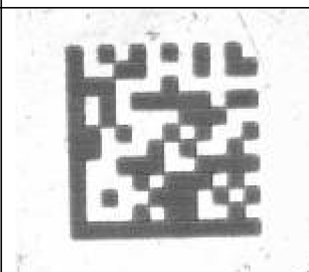
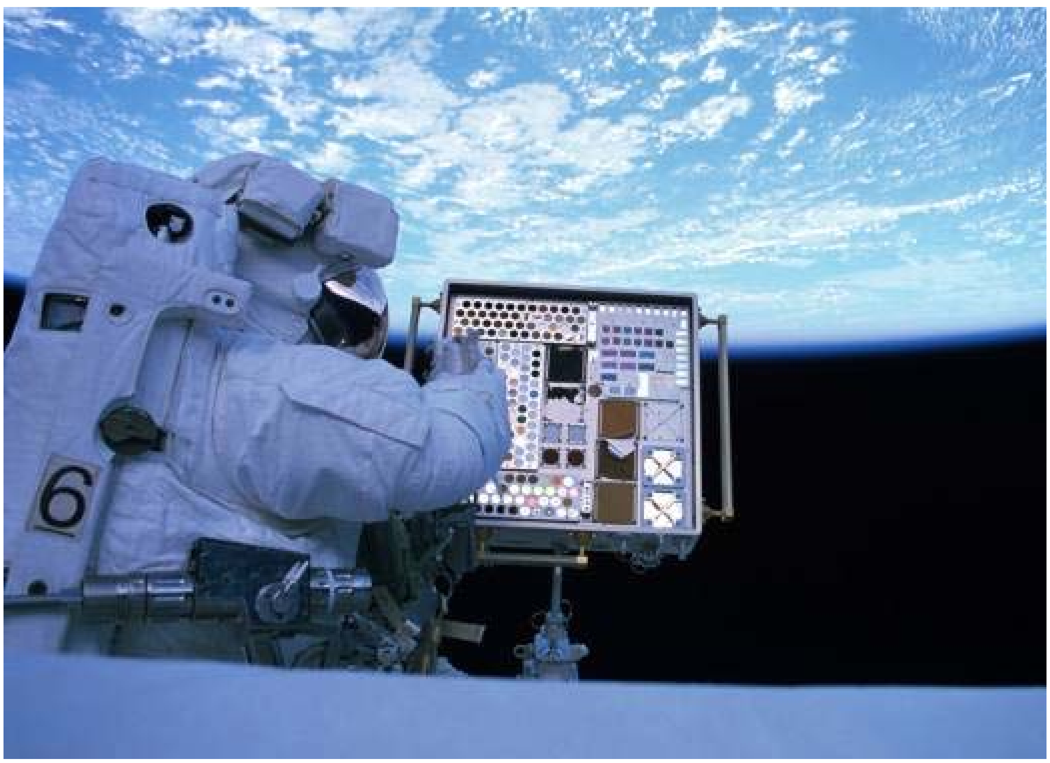
Sample Number	Marking Comparison			
	Pre-Flight Mark Photograph	Pre-Flight Verification Grade	Post-Flight Mark Photograph	Post-Flight Verification Grade
B-2-E16-44 LISI		% Contrast A Axial Uniformity A Print Growth A Error Correction A Overall Grade A		% Contrast A Axial Uniformity A Print Growth A Error Correction A Overall Grade A
B-2-E16-45 Laser Shotpeen		% Contrast A Axial Uniformity A Print Growth B Error Correction A Overall Grade B		Mark Unchanged - Symbol to small to decode or grade using latest Verification Standards. No visible degradation of marking
B-2-E16-46 LIVD - Tin		% Contrast A Axial Uniformity A Print Growth A Error Correction A Overall Grade A		% Contrast A Axial Uniformity A Print Growth A Error Correction A Overall Grade A

Table 5. MISSE 3 and 4 Pre-Flight and Post-Flight Comparison (Continued).

Sample Number	Marking Comparison			
	Pre-Flight Mark Photograph	**Pre-Flight Verification Grade**	**Post-Flight Mark Photograph**	**Post-Flight Verification Grade**
B-1-E4-46 Electro-Chemical Coloring		% Contrast A Axial Uniformity A Print Growth A Error Correction A Overall Grade A		% Contrast A Axial Uniformity A Print Growth A Error Correction A Overall Grade A
B-1-D4-28 VAVD - Copper	Line Pattern	Excellent Contrast and Line Resolution	Sample being Evaluated by Boeing Phantom Works	N/A
B-1-D4-29 VAVD - Copper	Line Pattern	Good Contrast – Excellent Line Resolution	Sample being Evaluated by Boeing Phantom Works	N/A
B-1-D6-2 (Identified as B-1-E10-07)		% Contrast A Axial Uniformity A Print Growth B Error Correction A Overall Grade B		% Contrast B Axial Uniformity A Print Growth B Error Correction A Overall Grade B

MISSE 6 MARKING EXPERIMENTS

The original MISSE 6 launch target launch date was February 14, 2008 on STS-122. However, that mission was delayed and the experiments were launched at 2:28 am March 11, 2008 with mission STS-123. Space Shuttle Orbiter Endeavour was the vehicle used to execute this mission. Installation was attempted during the third EVA, however the case did not initially fit onto the bracket and installation was postponed. The MISSE 6 experiment was then installed successfully during the fifth EVA on March 22, 2008 by Astronauts Robert L. Behnken and Michael Foreman.



This photograph of MISSE 6 was taken immediately after being attached to an exterior truss segment on the Columbia External Payload Facility during STS-123. Other in-flight photographs were taken on September 1, 2009. These photographs showed readable Data Matrix™ symbols in all positions.

MISSE 6 was retrieved from outside the European Space Agency's Columbus Laboratory by STS-128 astronauts Danny Olivas and Nicole Stott on Sept. 1, 2009.

The experiments were returned to the DFRC, Edwards Air Force Base, California on September 11, 2009 after two landing attempts at KSC were waved off due to poor weather. Discovery touched down at 8:53 pm. Discovery began its trek back to KSC at daybreak on Sunday, September 20, 2009, when the spacecraft departed Edwards Air Force Base in California atop the modified 747 carrier jet. The duo made refueling stops in Amarillo and Fort Worth, Texas, before heading to Barksdale Air Force Base in Louisiana for an overnight stay. Space Shuttle Discovery completed its ferry flight across the country Monday, reaching the KSC just after 12 noon EDT on September 21, 2009.

The marked samples were hand carried to Sys-Tec Corporation for mark quality verification. This activity was completed on December 7, 2008.

Marking Processes Tested on MISSE 6

Four different additive marking processes were incorporated into MISSE 6. These processes were thermal transfer printing, laser markable aluminum label, laser engraveable 2-ply acrylic tape and laser markable paint. These marking processes are described as follows:

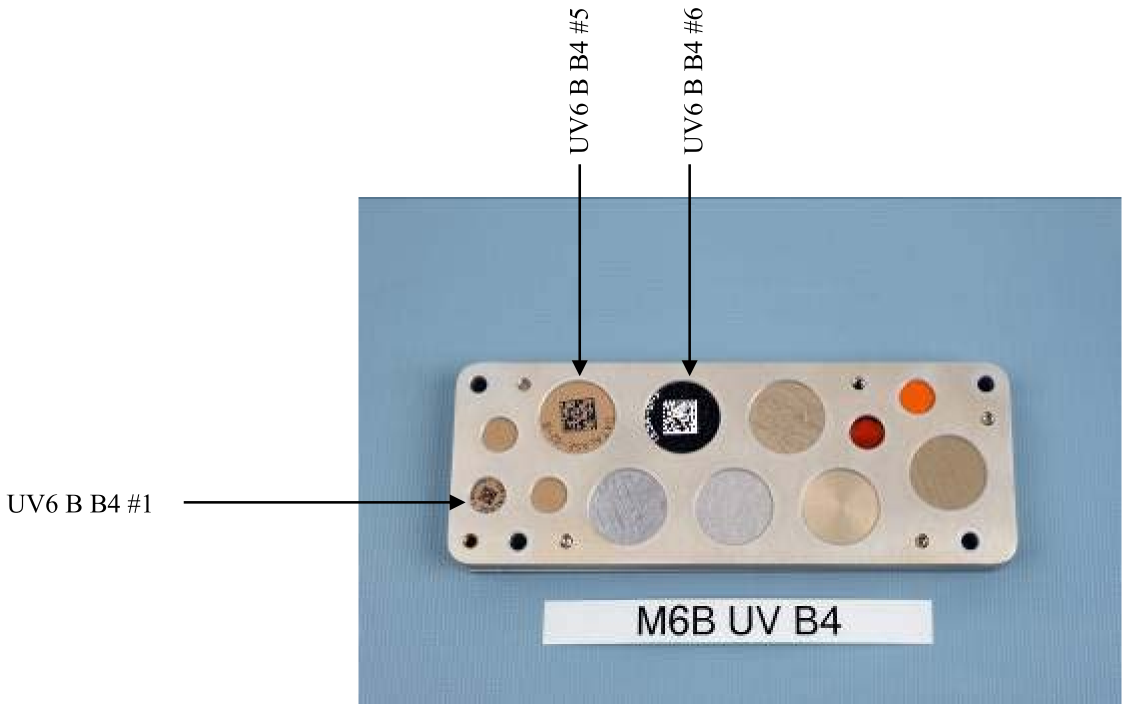
Thermal Transfer Printing - The thermal transfer process is accomplished in a thermal transfer printer by applying a voltage to the print head that consists of 200 to 600 resistive heating elements per linear inch (dots per inch). The resistive material is covered by a thin coating or "glaze" that protects the heating elements from abrasion as the thermal transfer ribbon makes contact with it. The line of print head elements is in direct pressure contact with the back-side of the thermal transfer ribbon. The ink side of the ribbon is in direct contact with the receiver or label stock. This ribbon and receiver "sandwich" is driven by a rubber-covered platen roller under the print head print line driven at a speed consistent with the heating cycle time of the print head. Heat from the printing elements raises the solid ink to a temperature above its melting point. At this time the ink from the ribbon transfers to the receiver and adheres to it. Together, the ribbon and receiver continue to move from under the print head for a short distance before separation of ribbon and receiver occurs. It is at this point that the image is formed.

Laser Markable Aluminum Label - Laser markable aluminum labels are covered with a proprietary silicone coating which is discolored by a CO_2 laser beam to create markings that are a tough and virtually mar-proof. The labels are attached via adhesives, riveting, nailing, etc. They are specifically designed to survive in abrasive environments.

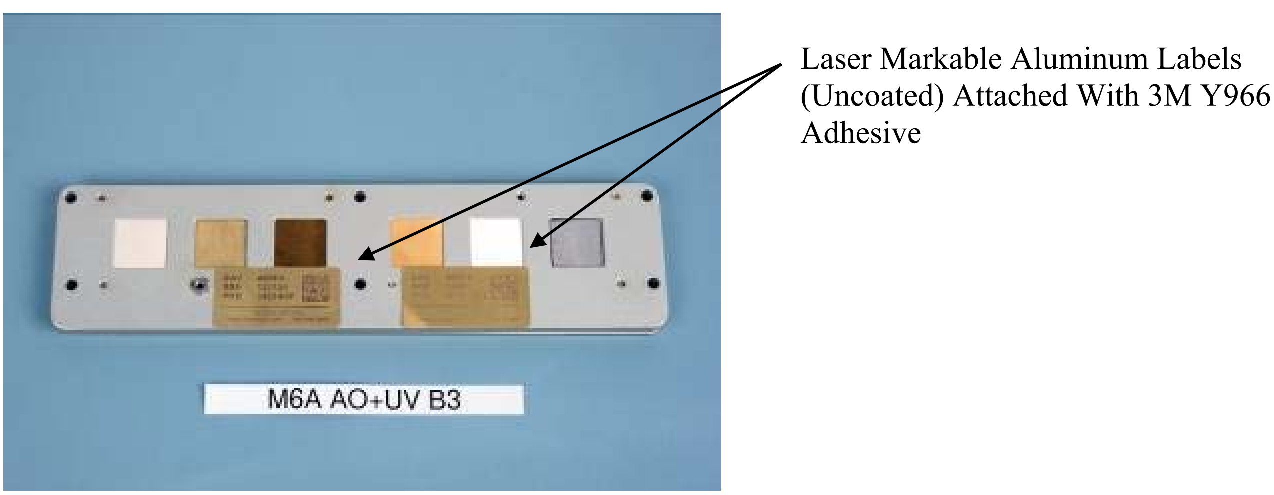
Laser Engraveable 2-Ply Acrylic Tape - Laser engravable 2-ply acrylic tape is a double-layered, highly polymerized acrylic label with an acrylic adhesive and a dimensionally stable liner. It is used in applications that require more durability than a typical printed label. Laser markable 2-ply acrylic tape is marked using the laser engraving process, which vaporizes material. The laser settings are set to remove the dark top layer of the tape to expose the underlying lighter colored layer.

Laser Markable Paint - Laser markable paints contain a chemical additive that changes color when struck by a laser beam containing the appropriate heat, light wavelength, and radiation, or a combination of these characteristics. The paint may be applied by brush or through an aerosol medium. In most cases, Coat and Discolor markings are covered with a clear coat for environment protection.

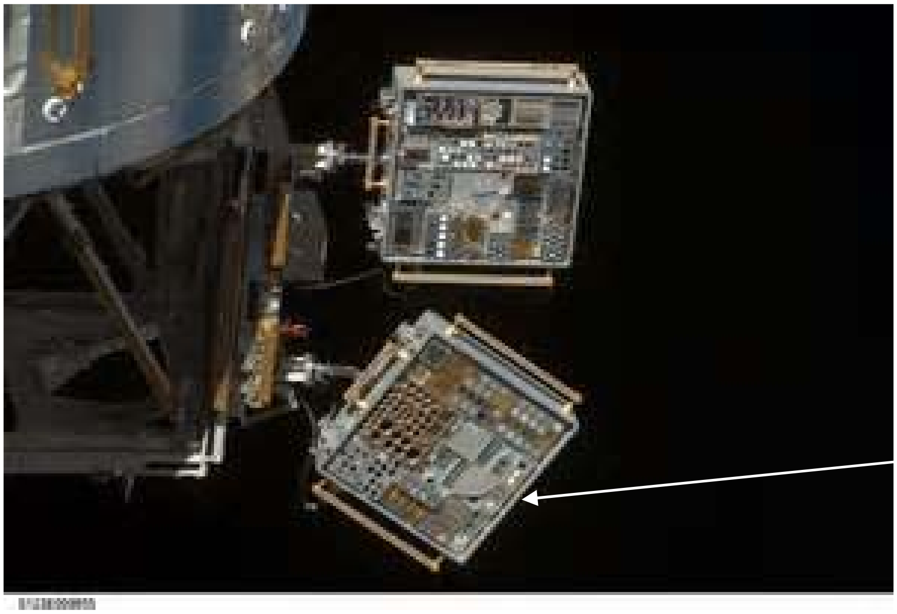
TEST COUPON POSITIONING ON THE MISSE 6 EXPERIMENT TRAYS



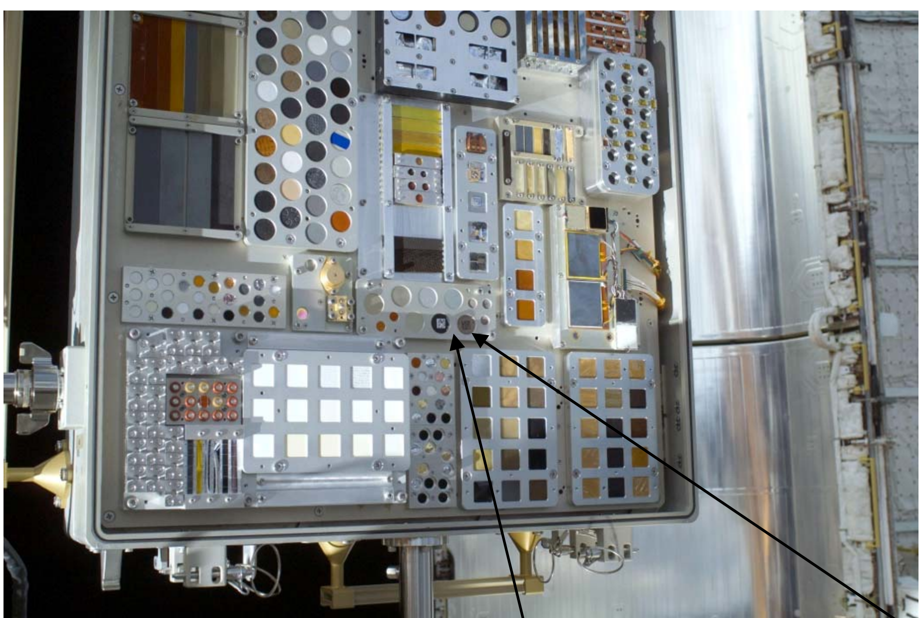
MISSE 6, PEC 6B, AO7 UV Tray 2 (Wake)



MISSE 6, PEC 6A AO and UV Tray 1 (Ram)



Laser Markable Aluminum Labels Installed on MISSE 6A



Laser Engraveable 2-Ply Acrylic Tape and Laser Markable Paint Test Coupons Installed on MISSE 6B

Table 6. MISSE 6 Pre-Flight Marking Grades.

Specimen Number	Base Material	Marking Method	Marking Material	Encoded Info.	Planned Orbit Duration	Color of Mark	Pre-Flight Grade	Marking Equipment
UV6-B-B4-6 Backside of Coupon	Aluminum	Thermal Transfer Printing	Resin Based Ink	Intermec 1	1 yr.	Black	A	Intermec PM4i Printer
UV6-B-B4-5 Large Mark	Aluminum	Laser Coloring	Laser Markable Paint With Clear Coat	123456	1 yr.	Black	B	Macsa 30 watt CO_2 Laser
UV6-B-B4-1 Small Mark	Aluminum	Laser Coloring	Laser Markable Paint With Clear Coat	123456	1 yr.	Black	B	Macsa 30 watt CO_2 Laser
Frame of M6A AO & UV B3, 2 Each	Aluminum	Laser Coloring	Laser Markable Aluminum Labels	123456	1 yr.	Black	A	InfoSight LL1000 Desk Top Laser
UV6-B-B4-6 Exposed Side of Coupon	Aluminum	Laser Engraving	Tesa Laser Markable Acrylic Tape	123456	1 yr.	Black	B	Macsa 30 watt CO_2 Laser

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Table 7. MISSE 6 Pre-Flight/Post-Flight Marking Comparison.

Sample Number	Marking Comparison			
	Pre-Flight Mark Photograph	Pre-Flight Verification Grade	Post-Fight Mark Photograph	Post-Flight Verification Grade
UV6-B-B4-6 Backside of Coupon		% Contrast A Axial Uniformity A Print Growth A Error Correction A Overall Grade A		% Contrast A Axial Uniformity A Print Growth A Error Correction A Overall Grade A
Laser Markable Paint - Small		% Contrast A Axial Uniformity A Print Growth A Error Correction A Overall Grade A		% Contrast A Axial Uniformity A Print Growth A Error Correction A Overall Grade A
Laser Markable Paint - Large		% Contrast B Axial Uniformity A Print Growth A Error Correction A Overall Grade B		% Contrast A Axial Uniformity A Print Growth A Error Correction A Overall Grade A

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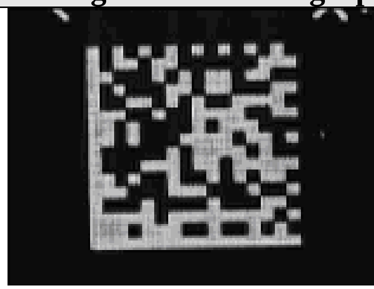
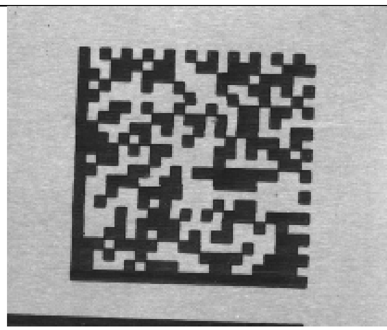
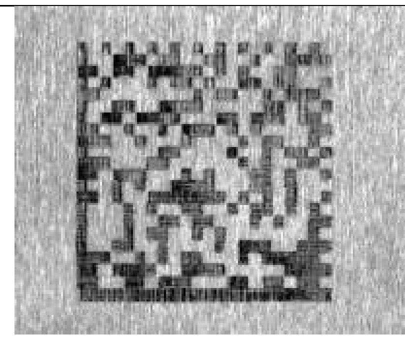
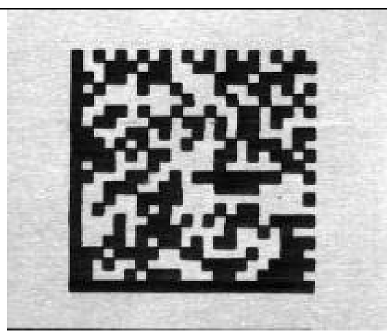
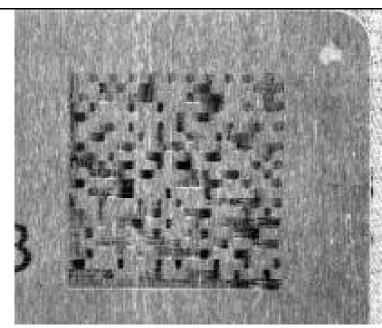
Table 7. MISSE 6 Pre-Flight/Post-Flight Marking Comparison (Continued).

Sample Number	Marking Comparison			
	Pre-Flight Mark Photograph	Pre-Flight Verification Grade	Post-Flight Mark Photograph	Post-Flight Verification Grade
UV6-B-B4-6 Exposed Side of Coupon		% Contrast A Axial Uniformity A Print Growth B Error Correction A Overall Grade B		% Contrast A Axial Uniformity A Print Growth A Error Correction A Overall Grade A
Frame of M6A AO & UV B3, Sample 1		% Contrast A Axial Uniformity A Print Growth A Error Correction A Overall Grade A		% Contrast A Axial Uniformity A Print Growth A Error Correction A Cell Modulation D Row Modulation D Overall Grade D
Frame of M6A AO & UV B3, Sample 2		% Contrast A Axial Uniformity A Print Growth A Error Correction A Overall Grade A		Could not be decoded

MISSE 8 MARKING EXPERIMENTS

MISSE 8, the final materials experiment to be flown on the Space Shuttle Program, was launched at 8:56 a.m. on March 16, 2011 aboard STS-134.

During Extra Vehicular Activity, astronauts mounted MISSE 8 on the ExPRESS Logistics Carrier 2 (ELC-2), which was located on the S3 Truss Outboard Zenith site. MISSE-8 reused the mounting and power/data infrastructure on the MISSE 7 ExPRESS Pallet Adapter (ExPA). Throughout the deployment of MISSE 8, crewmembers captured photographs of the PEC.

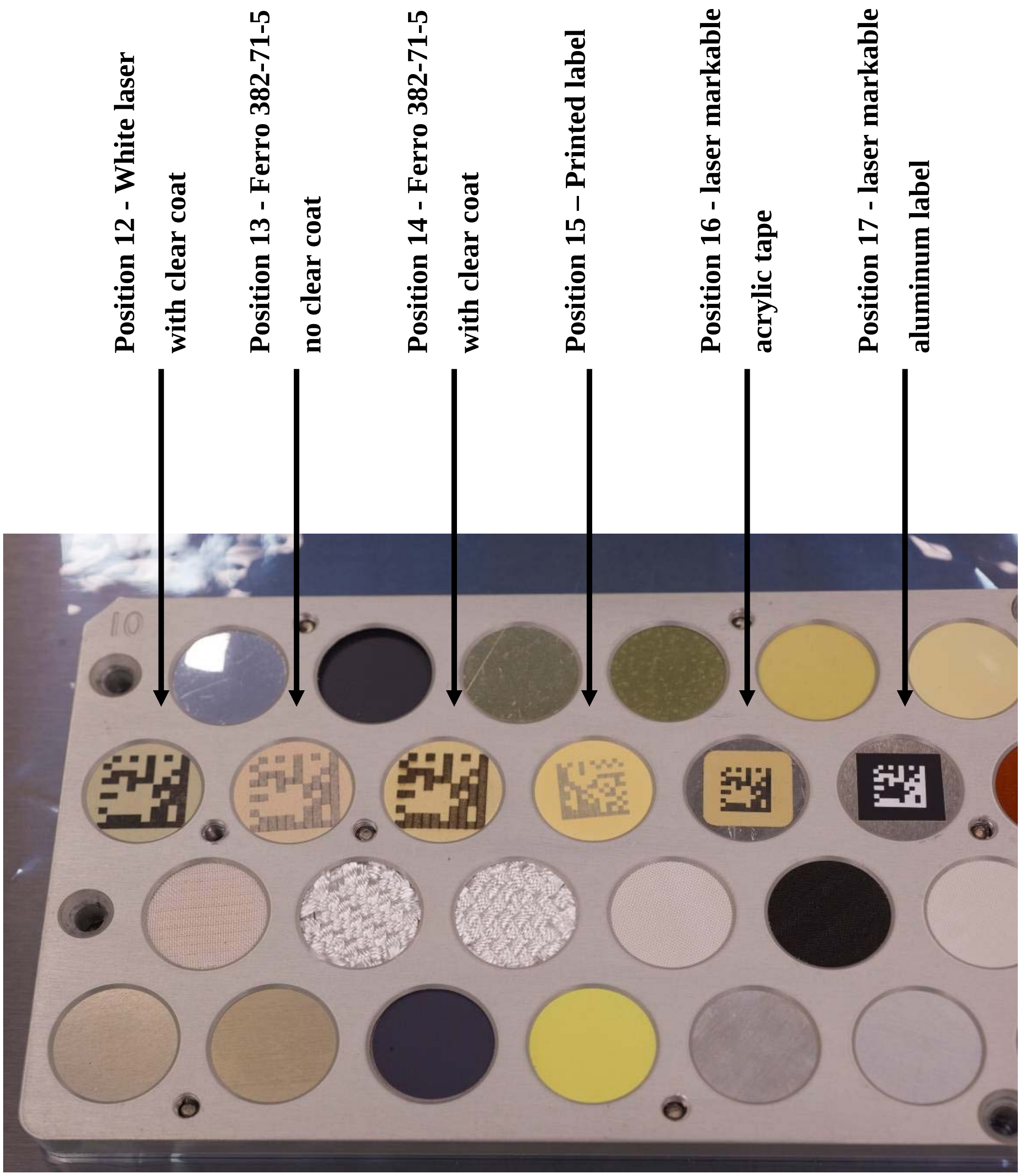
MISSE 8 Installed on ExPRESS Logistics Carrier 2 (ELC-2), May 20, 2011 (Photographed by Astronaut Ron Garan STS-135 on July 12, 2011)

MISSE 8 was retrieved via EVA on July 17, 2013 and returned inside the SpaceX Dragon capsule as part of the SpX-5 mission. The unpiloted Dragon splashed down in the Pacific Ocean, about 300 miles west of Baja, California, just five hours after leaving the International Space Station at 9:26 am, May 18, 2014.

Marking Processes Tested on MISSE 8

Six different marking processes were tested on MISSE 8. These included advanced versions of the materials flown on MISSE 6. The Datalase laser markable paint was replaced with a more robust paint developed by the Ferro Corporation. The printed labels manufactured by Intermec Corporation were replaced with a more substantial label developed by 3M. The laser markable tape was replaced by a different, less expensive version manufactured by 3M, and the laser markable aluminum labels manufactured by InfoSight Corporation were flown again with a protective clear coat to prevent fading.

TEST COUPON POSITIONING ON THE MISSE 8 EXPERIMENT TRAY



MISSE 8, PEC Tray M8B

List of Tables

Table 8. MISSE 8 Pre-Flight Marking Grades.

Specimen Number	Base Material	Marking Method	Marking Material	Encoded Info.	Planned Orbit Duration	Color of Mark	Pre-Flight Grade	Marking Equipment
M8B-12	Aluminum	Laser Coloring	Laser Markable High Temperature Paint With Clear Coat	123456	1 yr.	Black	A	Macsa 30 watt CO_2 laser
M8B-13	Aluminum	Laser Coloring	Laser Markable Paint Without Clear Coat	123456	1 yr.	Black	A	Macsa 30 watt CO_2 laser
M8B-14	Aluminum	Laser Coloring	Laser Markable Paint With Clear Coat	123456	1 yr.	Black	A	Macsa 30 watt CO_2 laser
M8B-15	Aluminum	Thermal Transfer Printing	3M Resin Based Ink	123456	1 yr.	Black	A	Printer
M8B-16	Aluminum	Laser Engraving	3M Laser Markable Acrylic Tape	123456	1 yr.	Black	A	Macsa 30 watt CO_2 laser
M8B-17	Aluminum	Laser Coloring	Laser Markable Aluminum Labels With Clear Coat	123456	1 yr.	Black	A	InfoSight LL1000 Desktop Laser

List of Tables

Table 9. MISSE 8 Pre-Flight/Post-Flight Marking Comparison.

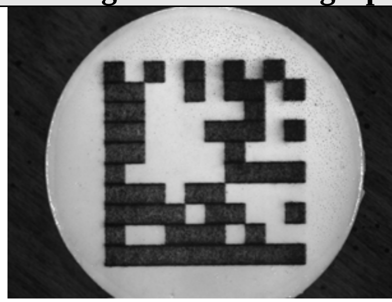
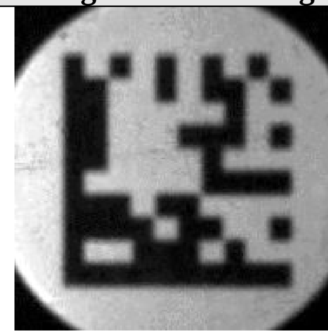
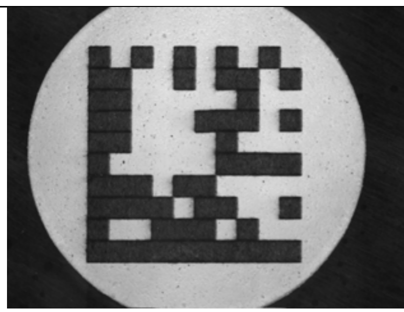
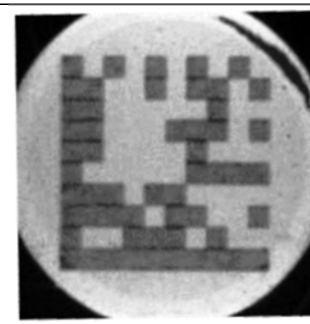
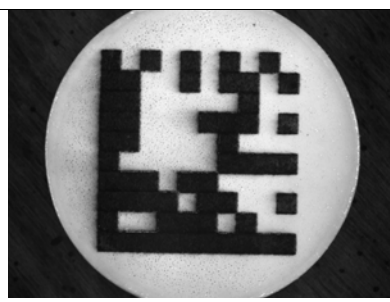
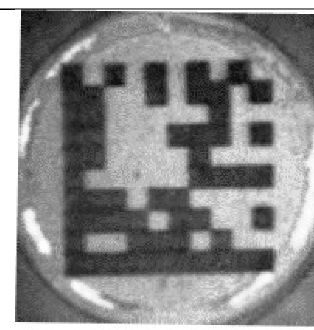
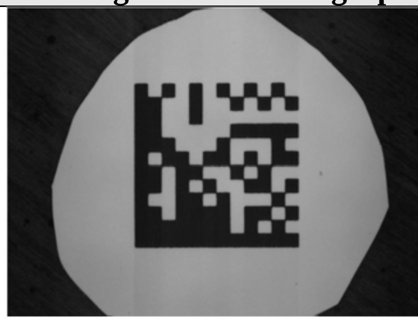
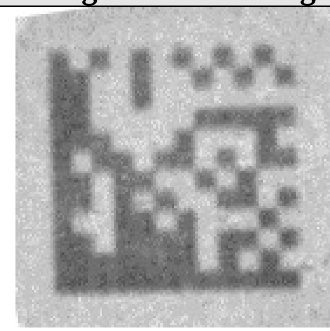
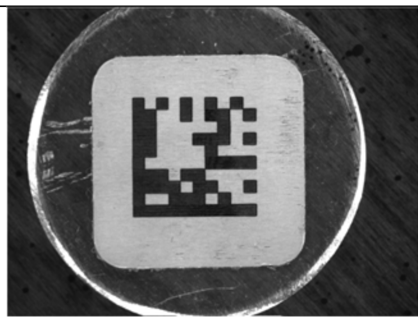
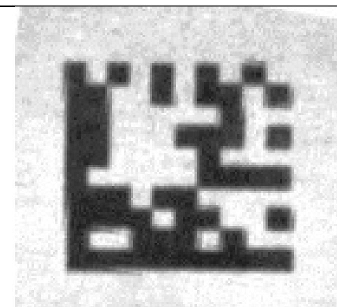
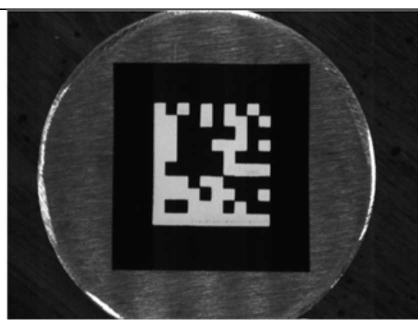
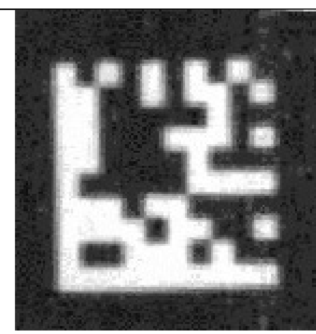
Sample Number	Marking Comparison			
	Pre-Flight Mark Photograph	Pre-Flight Verification Grade	Post-Flight Mark Photograph	Post-Flight Verification Grade
M8B-12 InfoSight 40353 High Temp Paint With Clear Coat		% Contrast A Axial Uniformity A Print Growth A Error Correction A Overall Grade A		% Contrast C Axial Uniformity A Print Growth A Error Correction A Overall Grade C
M8B-13 Ferro 382-71-5 Lab # 6795B Paint Without Clear Coat		% Contrast A Axial Uniformity A Print Growth A Error Correction A Overall Grade A		% Contrast C Axial Uniformity A Print Growth A Error Correction A Overall Grade F
M8B-14 Ferro 382-71-5 Lab # 6795B Paint With Clear Coat		% Contrast A Axial Uniformity A Print Growth A Error Correction A Overall Grade A		% Contrast C Axial Uniformity A Print Growth A Error Correction A Overall Grade F

Table 9. MISSE 8 Pre-Flight/Post-Flight Marking Comparison (Continued).

Sample Number	Marking Comparison			
	Pre-Flight Mark Photograph	**Pre-Flight Verification Grade**	**Post-Flight Mark Photograph**	**Post-Flight Verification Grade**
M8B-15 3M Thermal Transfer Printed Label		% Contrast A Axial Uniformity A Print Growth A Error Correction A Overall Grade A		% Contrast D Axial Uniformity A Print Growth A Error Correction A Overall Grade D
M8B-16 InfoSight Laser Markable Aluminum Label		% Contrast A Axial Uniformity A Print Growth A Error Correction A Overall Grade A		% Contrast A Axial Uniformity A Print Growth A Error Correction A Overall Grade A
M8B-17 3M 7847 Laser Markable Two-Ply Acrylic Tape		% Contrast A Axial Uniformity A Print Growth A Error Correction A Overall Grade A		% Contrast B Axial Uniformity A Print Growth A Error Correction A Overall Grade B

SUMMARY

The primary purpose for the MISSE marking tests was to define Data Matrix™ symbol marking processes that will remain readable after exposure to Low Earth Orbit environments. A wide range of different Data Matrix™ symbol marking processes and materials, including some still under development, were evaluated.

The samples flown on MISSE 1 and 2 were in orbit for 3 years and 348 days, MISSE 3 and 4 were in orbit for 1 year and 15 days, MISSE 6 was in orbit for 1 year and 130 days, and MISSE 8 was in orbit for 2 years and 55 days.

The initial MISSE marking tests clearly reflected that intrusive marking processes can be successfully used for this purpose. All of the intrusive marking processes tested exceeded program expectations and met 100 percent of the principle investigators objectives.

However, subsequent tests demonstrated that some additive marking processes will also satisfy the requirements. This was an unexpected result.

All of the markings retrieved from orbit remained readable with the exception of one: a laser markable aluminum label without clear coat (AO & UV B3 Sample 2) attached to the frame of M6A on MISSE 6. Five others remained readable, but failed mark quality verification. These were:

- A laser markable aluminum label without clear coat (AO & UV B3 Sample 1) attached to the frame of M6A on MISSE 6 – Grade D.
- Laser markable high temperature paint with clear coat. Sample number M8B-12 flown on MISSE 8 – Grade C.
- Laser markable paint without clear coat. Sample number M8B-13 flown on MISSE 8 - Grade F.
- Laser markable paint with clear coat. Sample number M8B-14 flown on MISSE 8 - Grade F.
- Thermal transfer printed label. Sample number M8B-15 flown on MISSE 8 - Grade D.

Each of the failures noted above were a result of contrast reduction attributed to a combination of exposure to strong UV light and atomic oxidation.

Three marking processes improved during flight. The mark quality of specimen number B-1-E4-44 (Laser Coat and Remove - VAVD) improved over the four years in orbit. The contrast levels for this specimen increased as the copper colored coating darkened to a dark green as a result of oxidation. This specimen was the only one to show signs of micro-partical impact during flight. The impact sites could only be viewed under high magnification and did not have an affect on decoding. This specimen also showed signs of discoloration outside of the marking area, which was attributed to marking process deficiencies caused by contamination in the coating sprayed on the metal at the time of coating. This contamination resulted in coating discoloration after exposure to the LEO environment.

The Laser Markable Paint sample (UV6 B B4-5) graded B before flight and graded A after being in orbit 1 year and 130 days. The improvement was a result of a slight fading of the unmarked paint which resulted in improved contrast between the mark and the background. The Tesa Tape sample (UV6-B-B4-6) also graded B before flight and graded A after 1 year and 130 days in orbit. The verification software showed an improvement in print growth. The pre-flight grade was border line. A detailed examination of the mark showed no difference in symbol mark detail and the grade change is believed to be a result of improved verification software and slightly better lighting during Post-Flight grading.

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
01–10–2015

2. REPORT TYPE
Contractor Report

3. DATES COVERED *(From - To)*
April 2000–September 2015

4. TITLE AND SUBTITLE
Marking Tests to Certify Part Identification Processes for Use in Low Earth Orbit

5a. CONTRACT NUMBER
Multiple

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
D.L. Roxby

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
George C. Marshall Space Flight Center, Huntsville, AL 35812
Viking Consulting, 128 Victorian Rose Lane, Gurley, AL 35748

8. PERFORMING ORGANIZATION REPORT NUMBER
M–1404

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Washington, DC 20546–0001

10. SPONSORING/MONITOR'S ACRONYM(S)

11. SPONSORING/MONITORING REPORT NUMBER
NASA/CR—2015–218215

12. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified-Unlimited
Subject Category 35
Availability: NASA STI Information Desk (757–864–9658)

13. SUPPLEMENTARY NOTES
Prepared for the Materials and Processes Laboratory, Engineering Directorate
COTR: Miria M. Finckenor

14. ABSTRACT
Qualifying marking processes for long-term use in space is especially challenging because this unique environment is difficult to simulate in the laboratory. Consequently, NASA designed the Materials International Space Station Experiment (MISSE) to subject materials to the harsh environment seen in low Earth orbit. These environmental conditions include, but are not limited to, vacuum, solar ultraviolet radiation, micrometeoroids and space debris, atomic oxygen, and deep thermal cycles. Marking experiments were incorporated into four different MISSE packages. The results of these four experiments are consolidated into this final report.

15. SUBJECT TERMS
part making, identification, space environment, engraving, etch, laser

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES
U	U	U	UU	62

19a. NAME OF RESPONSIBLE PERSON
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