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

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ABSTRACT

Prior to the Space Shuttle Program, space-borne vehicles launched into space were expended; consequently their part identifiers were applied using marking processes designed for use in ground operations. With the advent of reusable space transportation vehicles and retrievable satellites, NASA needed to rethink how part identification markings are applied to their space borne vehicles. Markings applied to reusable spacecraft need to survive the extreme environments encountered in space. To support this new requirement, NASA approached RVSI (now Siemens) to assist with a marking program to certify marking(s) for use in Low Earth Orbit (LEO).

An experiment was designed to identify part identification methods and techniques that might survive the rigors of space. The experiment was to be designed to expose both human and machine-readable markings to LEO environments. These include, but are not limited to, vacuum, solar UV radiation, micrometeoroids and space debris, atomic oxygen (AO) and deep thermal cycles. Two specimen packages were assembled. The first package was incorporated into MISSE 1 and 2 (one year orbital experiments) and consisted of currently approved marking processes and number of newly developed Laser Additive marking techniques deemed safe for use in safety critical applications. The second package contained a series of more robust intrusive marking technique that utilized higher-powered laser markers. These specimens were incorporated in MISSE 3 and 4, which was scheduled to fly in orbit for three years. This report describes the results of the MISSE 1 and 2 marking experiments.

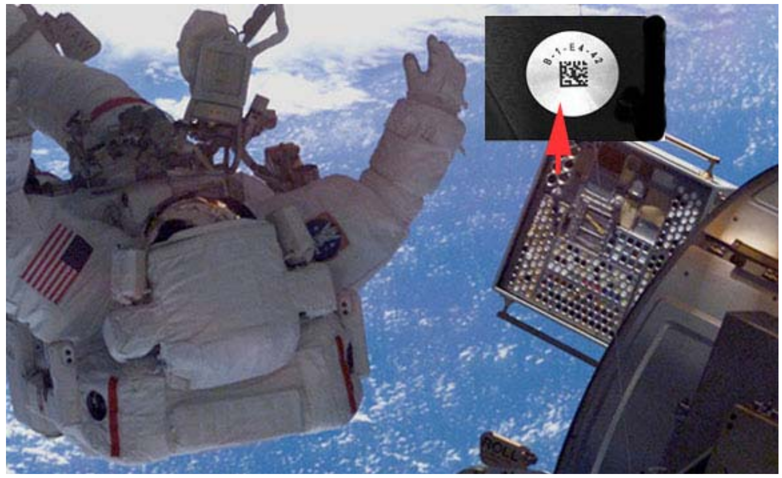
International Space Station In Low Earth Orbit

INTRODUCTION

Working with the Boeing Phantom Works, Siemens's (formally RVSI) Symbology Research Center applied 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 structural components (anodized and painted aluminum), thermal protection system (TPS) blankets (beta cloth) and glass (windows, mirrors, lenses). TPS tile markings were not included, having been previously tested by an RVSI Researcher on a previous space shuttle program. The test coupons incorporated into MISSE 1 and 2 consisted of 17 marked 0.995-inch diameter disks. These coupons were marked using currently approved marking processes (Dot Peen and Electro-Chemical coloring) and new additive laser marking processes. These included laser inducted vapor deposition (LIVD), Laser Bonding to both metal and glass, Gas Assisted Laser Etch (GALE) and a Laser Coat and Remove process that involved the use of Vacuum Arc Vapor Deposition (VAVD). Additional intrusive laser marking processes designed for survivability on longer duration mission were incorporated into MISSE 3 and 4. These included Direct Laser Etch, Laser Shot Peening and Laser Induced Surface Improvement (LISI). MISSI 3 & 4 also include marking processes for thermal blankets and a 6-inch plate marked with containing symbol of different sizes to be used to establish the minimum data cell size to be used in LEO applications.

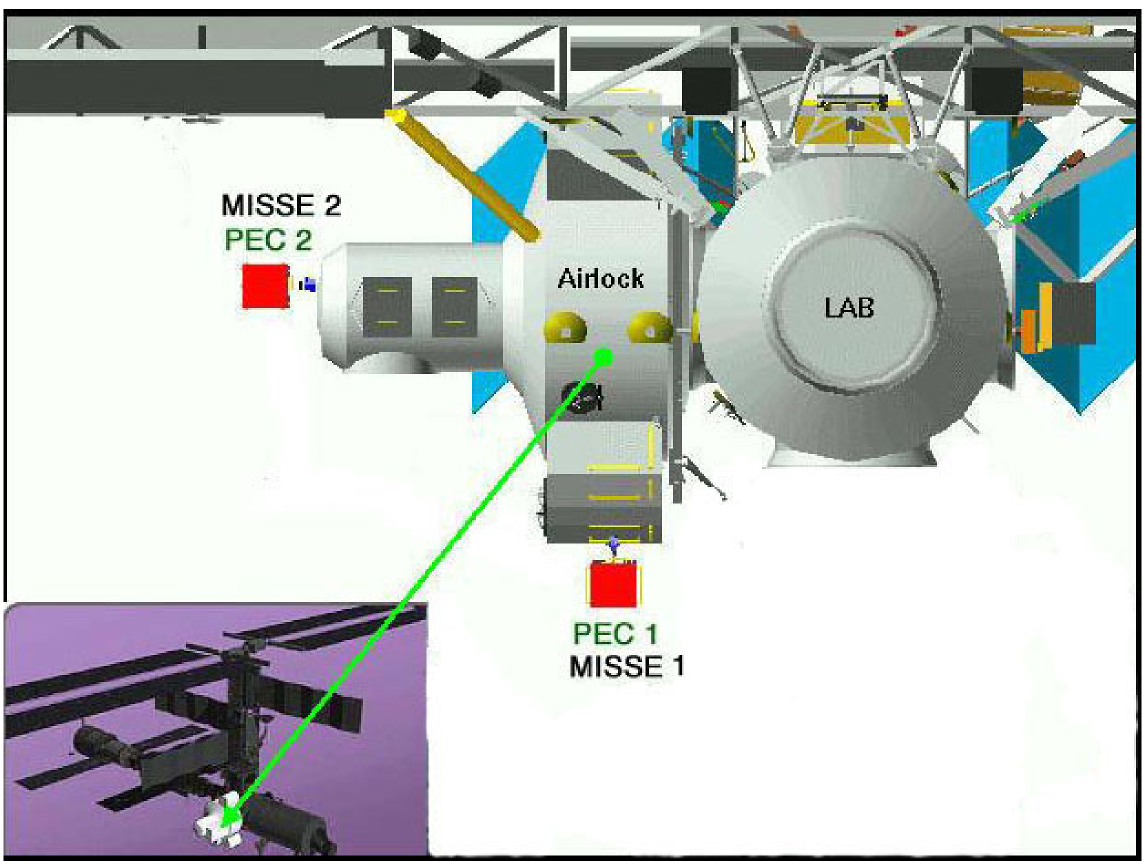
The marked material test coupons were affixed to spaces provided on test panels, which were then installed onto trays identified as Material - International Space Station - Experiment (MISSE). These experiments were then installed into two suitcase like structures, called Passive Experiment Containers (PECs). MISSE 1 and 2 where were attached to the International Space Station (ISS) by Astronaut Patrick G. Forrester during a space walk conducted during the STS-105 Mission, which was launched on August 10, 2001.

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



MISSE Positioned on Exterior of the International Space Station by Mission Specialist Patrick 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 ultra-violet (UV) radiation and atomic oxidation (AO). PEC-2 was positioned on the side of the ISS Airlock to receive UV radiation, but minimal amount exposure to atomic oxygen.

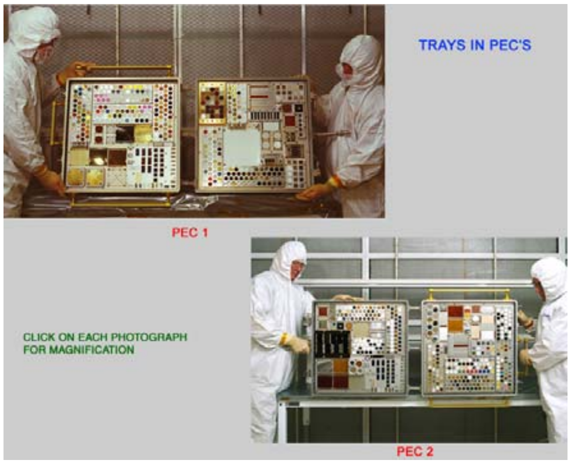


The original plan called for MISSE 1 and 2 to be retrieved after 1 year. After their recovery, MISSE 3 and 4 were to be launched into LEO and retrieved after 3 years. The Columbia incident, however, delayed retrieval of the MISSE 1 and 2 experiments until the second mission following return to flight (STS-115). 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 six hours 50 minutes space walk. The experiments were subjected to a total 1443 days of LEO exposure, or just 17 days short of 4 years.

MISSE 1 and MISSE 2 were returned to earth on August 10, 2005. As a result of bad weather (low cloud cover) at the Kennedy Space Center (KSC), Discovery was forced to make a night Landing at the Dryden Flight Research Center (DFRC), Edwards Air Force Base (EAFB), California. The orbiter 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.

Columbia Lands At EAFB at end of the STS-114 Mission

The Orbiter arrived at KSC on August 20,2005 and was towed from the Shuttle Landing Facility to the Orbiter Processing Facility 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 Labortory at NASA's Langley Research Center (LARC), Hampton, Virginia, where the PEC's were inspected, disassembled and photographed. The marked coupons were then hand carried back to the Siemens Symbology Research Center where mark quality was analyzed and decoding tests conducted to qualify identification processes for future retrievable spacecraft and satellites.



PEC's 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 C, " Application Of Data Matrix Identification Symbols To Aerospace Parts Using Direct Part Marking Methods/Techniques " The standard updates were also provided to the USAF for possible inclusion into MIL-STD-130**, "**Identification Marking Of U.S. Military Property **."**

MARKING PROCESSES TESTED

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

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

Electro-Chemical Coloring - Electro-chemical coloring marks are produced using an electro-chemical process used in conjunction with a stencil to form a marking. In this process, metal is removed and replaced using an alternating current 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 used.

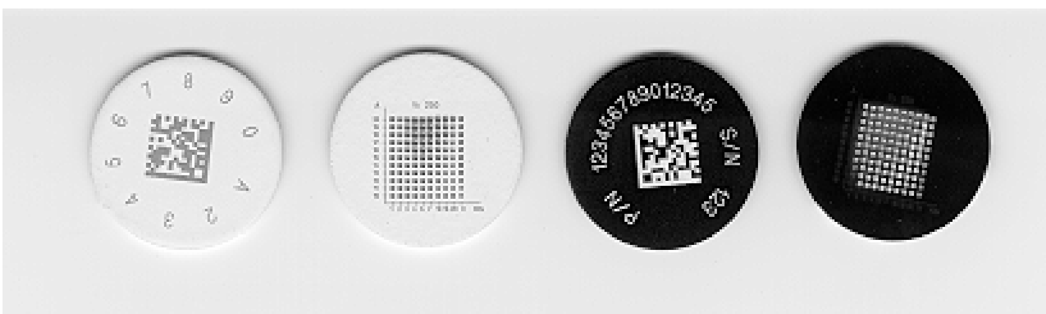
Laser Bonding - Laser bonding is an additive process that involves the bonding of a material to the substrate surface using the heat generated by an Nd:YAG, YVO4, or carbon dioxide (CO_2) laser. The materials used in this process are commercially available, and generally consist of a glass-frit powder 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 are safe for use in safety-critical applications. The markings produced using this technique (dependent on the material used), are resistant to high heat, unaffected by salt fog/spray, and are extremely durable.

Laser Coat (VAVD) and Remove - 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 the firing time.

Laser Inducted Vapor Deposition (LIVD) – The LIVD process, developed by Siemens, 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 seal gas/vacuum chambers.

TEST COUPON CONFIGURATIONS

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



Sample 0.995-Inch Diameter Coupons Created To Test Marking Processes

Table 1 defines the substrate materials used in the construction of the 0.995-inch disks. It also includes the marking process, marking device, marking media and protective coatings used in their identification. The table also includes the technical contacts associated with the marking of each of the disks.

Table 1 - Part Identification Markings Generated for MISSE 1 through 4

Marking Category	Coupon No.	Marking Method	Marking Device	Marking Media	Substrate Material	Protective Coating	Technical Contacts
Additive Marking	Disk 1	Laser Bonding	CO2 Laser	Cerdec LMM-6000 Metal Coating	Anodized AL	None	Don Roxby, CiMatrix - (256) 830-8123, Andy Axtell, Cerdec - (724) 250-5501 & Jennifer Bunis, Synrad - (800) 796-7231
	Disk 2	Laser Bonding	LVO4 Laser	Cerdec LMM-6000 Metal Coating	Anodized AL	None	Don Roxby, CiMatrix - (256) 830-8123, Andy Axtell, Cerdec - (724) 250-5501 & Mark Villand, LMT - (303) 664-9000 ext 624
	Disk 3	Laser Bonding	Nd:YAG Laser	Cerdec LMM-6000 Metal Coating	Anodized AL	None	Don Roxby, CiMatrix - (256) 830-8123 & Andy Axtell, Cerdec - (724) 250-5501 Eva Tang, Rofin-Sinar Laser – (480) 777-1199
	Disk 4	Laser Bonding	CO2 Laser	Ink – Markem 2700 Heat Cure (Black)	Anodized AL	VAVD – Aluminum Oxide	Don Roxby, CiMatrix – (256) 830-8123 & Lisa Siewierski, Markem – (603) 352-1130 Ext. 2219.
	Dusk 5	Ink Jet	Domino Ink Jet	Ink – Domino 262BK & 211WT (UV curable)	Anodized AL	VAVD – AL Oxide	Don Roxby, CiMatrix – (256) 830-8123 & Lyle Zickuhr, Domino – (847) 244-2501 x1128
	Disk 6	Stencil – Ink	Intermec Silk Screen Generator	Ink –Standard Silk Screen Ink	Anodized AL	VAVD – AL Oxide	Don Roxby, CiMatrix – (256) 830-8123 & Ron Pickman, Intermec – (203) 264-9476
	Disk 7	Stencil – VAVD	Laser Cut Vinyl Stencil	Gold	Anodized AL	None	Don Roxby, CiMatrix – (256) 830-8123, Leonard Adcock, UAH – (256) 890-6020 & Jack L Weeks, VAT - (256) 582-5484
	Disk 8	Laser Bonding	CO2 Laser	Cerdec LMM-6000 Metal Coating	AZ93 Coating	None	Don Roxby, CiMatrix – (256) 830-8123, Jennifer Bunis, Synrad – (800) 796-7231, Andy Axtell, Cerdec - (724) 250-5501 & Richard Mell, AZTek – (256) 837-9877, ext. 135
	Disk 9	Laser Bonding	LVO4 Laser	Cerdec LMM-6000 Metal Coating	AZ93 Coating	None	Don Roxby, CiMatrix – (256) 830-8123, Andy Axtell, Cerdec - (724) 250-5501, Mark Villand, LMT – (303) 664-9000 ext 624 Richard Mell, AZTek – (256) 837-9877, ext. 135

Table 1 - Part Identification Markings Generated for MISSE 1 Through 4 Continued

Marking Category	Coupon No.	Marking Method	Marking Device	Marking Media	Substrate Material	Protective Coating	Technical Contacts
Additive Markings	Disk 10	Laser Bonding	Nd:YAG Laser	Cerdec LMM-6000 Metal Coating	AZ93 Coating	None	Don Roxby, CiMatrix – (256) 830-8123, Eva Tang, Rofin-Sinar Laser – (480) 777-1199, Andy Axtell, Cerdec - (724) 250-5501 & Richard Mell, AZTek – (256) 837-9877, ext. 135
	Disk 11	Laser Bonding	CO2 Laser	Ink – Markem 2700 Heat Cure (Black)	AZ93 Coating	VAVD – Aluminum Oxide	Don Roxby, CiMatrix - (256) 830-8123, & Lisa Siewierski, Markem - (603) 352-1130 ext. 2219 & Richard Mell, AZTek – (256) 837-9877, ext. 135.
	Disk 12	Ink Spray	Ink Jet Marker	Ink – Domino 262BK & 211WT (UV curable)	AZ93 Coating	VAVD – Aluminum Oxide	Don Roxby, CiMatrix - (256) 830-8123, Lyle Zickuhr, Domino - (847) 244-2501 ext. 1128 & Richard Mell, AZTek – (256) 837-9877
	Disk 13	Stencil – Ink	Laser Cut Vinyl Stencil	Ink – Standard Silk Screen Ink	AZ93 Coating	VAVD – Aluminum Oxide	Don Roxby, CiMatrix - (256) 830-8123, Richard Mell, AZTek – (256) 837-9877, ext. 135 & Eva Tang, Rofin-Sinar Laser – (480) 777-1199
	Disk 14	Stencil - VAVD	Intermec Silk Screen Generator	Gold	AZ93 Coating	None	Don Roxby, CiMatrix - (256) 830-8123, Jack L Weeks, VAT - (256) 582-5484, Ron Pickman, Intermec - (203) 264-9476 & Richard Mell, AZTek – (256) 837-9877, ext. 135
	Disk 15	Label Printing	Computype TBD	Computye Dye Sublimation Ink	Beta Cloth	None	Don Roxby, CiMatrix - (256) 830-8123 & Dian Ferrell, Computype - (727) 726-5594

Table 1 - Part Identification Markings Generated for MISSE 1 Through 4 Continued

Marking Category	Coupon No.	Marking Method	Marking Device	Marking Media	Substrate Material	Protective Coating	Technical Contacts
Coat & Mark	Disk 16	LIVD	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
	Disk 17	Laser Etch	CO2 Laser	VAVD - Material Gold	Anodized AL	None	Don Roxby CiMatrix - (256) 830-8123, Jack L Weeks, VAT - (256) 582-5484
	Disk 18	Laser Etch	LVO4 Laser	VAVD - Material Gold	Anodized AL	None	Don Roxby CiMatrix - (256) 830-8123, Jennifer Bunis, Synrad, (800) 796-7231 & Jack L Weeks, VAT - (256) 582-5484
	Dusk 19	Laser Etch	Nd:YAG Laser	VAVD - Material Gold	Anodized AL	None	Don Roxby, CiMatrix - (256) 830-8123 & Jack L Weeks, VAT - (256) 582-5484
	Disk 20	Laser Etch	Nd:YAG Laser	VAVD - Material Gold	AZ93 Coating	None	Don Roxby, CiMatrix - (256) 830-8123 & Jack L Weeks, VAT - (256) 582-5484
Direct Part Marking	Disk 21	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
	Disk 22	Dot Peen	Dot Peen Marker	Dot Peen	Bare AL	None	Don Roxby, CiMatrix - (256) 830-8123 & Richard Pentz, DAPRA - (800) 442-6275
	Disk 23	Laser Etch	Nd:YAG Laser	None	Bare AL	None	Don Roxby, CiMatrix - (256) 830-8123 & Eva Tang, Rofin-Sinar Laser – (480) 777-1199
	Disk 24	Electro-Chem Etch	Standard Pwr. Unit	Electrolyte	Bare AL	None	Don Roxby, CiMatrix - (256) 830-8123 & Sy Haeri, lectro-Chem Etch Metal Marking, Inc. (714) 671-7744
	Disk 25	GALE	LVO4 Laser	Marking Gas TBD	Bare AL	None	Don Roxby, CiMatrix - (256) 830-8123, Mary Helen McCay, UTSI - (931) 393-7473 & Mark Villand, LMT - (303) 664-9000 ext 624
	Disk 26	LISI	Nd:YAG Laser	TBD	Bare AL	None	Don Roxby, CiMatrix - (256) 830-8123, Mary Helen McCay, UTSI - (931) 393-7473 & Eva Tang, Rofin-Sinar Laser – (480) 777-1199

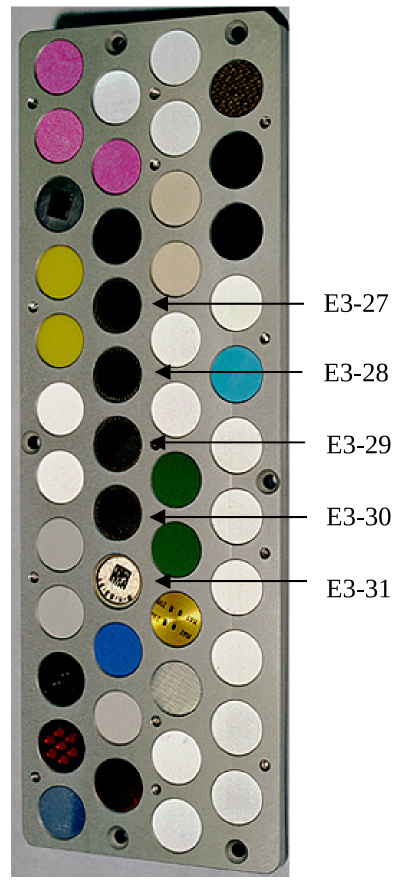
Table 1 - Part Identification Markings Generated for M-ISS-E 1 Through 4 Continued

Marking Category	Coupon No.	Marking Method	Marking Device	Marking Media	Substrate Material	Protective Coating	Technical Contacts
Direct Part Marking	Bar 1	Laser Etch	Nd:YAG Laser	None	Bare AL	None	Don Roxby, CiMatrix - (256) 830-8123 & Eva Tang, Rofin-Sinar Laser – (480) 777-1199
		Laser Etch	Nd:YAG Laser	None	Bare AL	Clear Anodize	Don Roxby, CiMatrix - (256) 830-8123 & Eva Tang, Rofin-Sinar Laser – (480) 777-1199

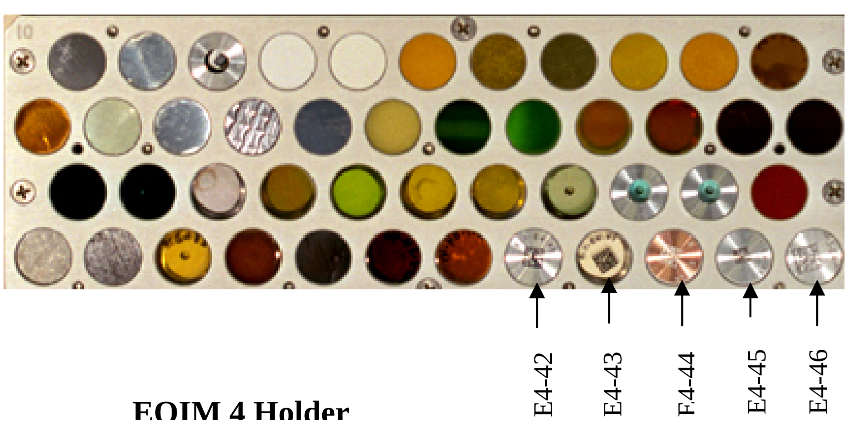
TEST COUPON POSTIONING ON THE EXPERIMENT TRAYS

The marked disks selected for flight were installed onto Experiment Holders 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

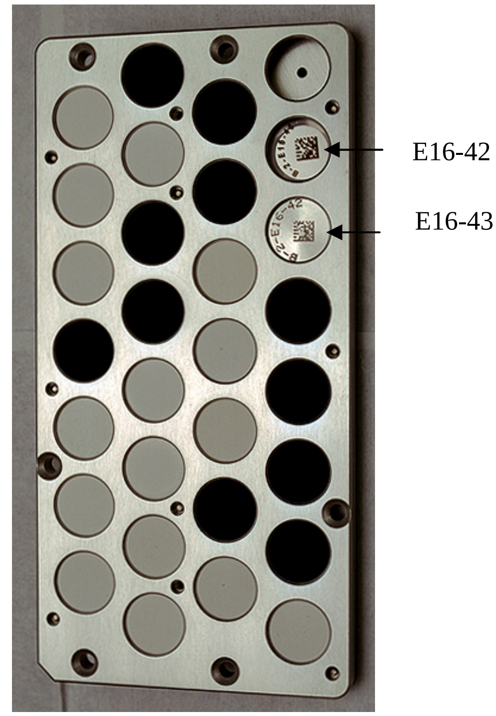


EOIM 3 Holder



EOIM 4 Holder

MISSE 2, Tray 2, Top



D2 Holder

EOIM 10 Holder (Flipped Horizontally)

PRE-FLIGHT GRADING

Each marked coupon to be flown was photographed under using a normal lens and under magnification prior to flight. These prints were stored to compare against samples after being exposed to the LEO environments. The Data Matrix Symbols were read and graded using RVSI's mark quality verification system and all scored "A."   The Pre-flight grades follow:

Table 2 – Pre-Flight Marking Grades Continued – MISSE 1 And 2

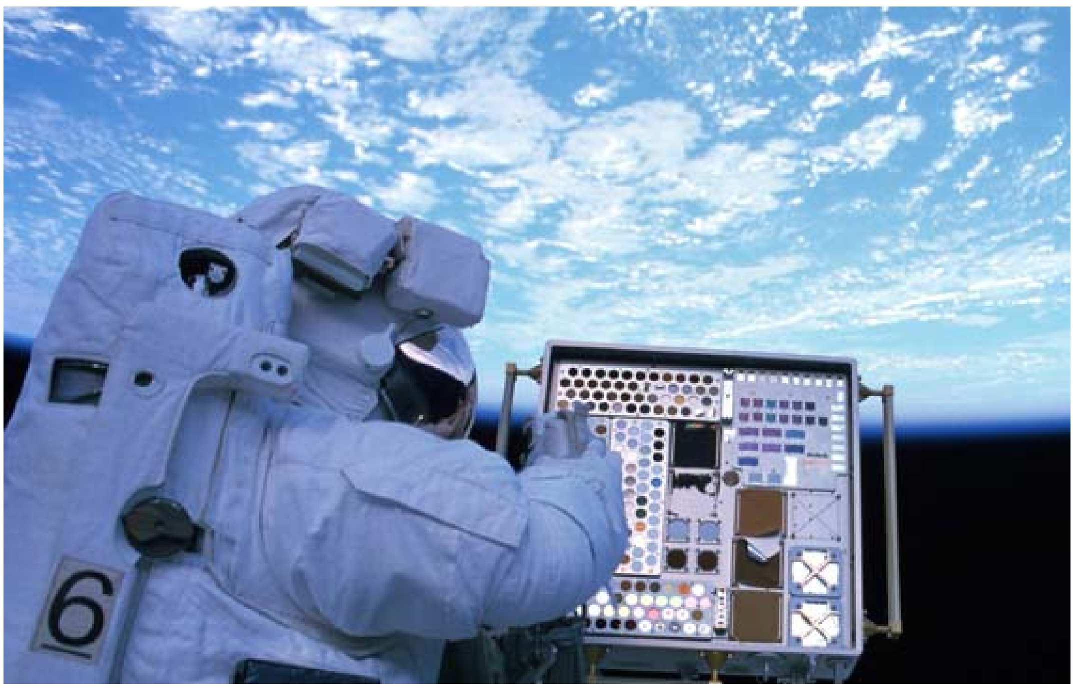
Specimen Number	Base Material	Marking Method	Marking Material	Encoded Info.	Planned Orbit Duration	Color of Mark	Pre Flight Grade	Marking Equipment
B-1-E10-06	Glass	VAVD	Copper	Line Pattern	1 yr.	Dark Gray	Good Contrast	Rofin-Sinar Nd:YAG Laser
B-1-E3-27	Glass	LIVD	Brass	Line Pattern	1 yr.	Dark Brown	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.	Dark Brown	Good 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-E10-07	Glass	LIVD	Brass	B1E107	1 yr.	Dark Brown	A	Rofin-Sinar Nd:YAG Laser

Table 3- Pre-Flight Marking Grades – MISSE 3 And 4

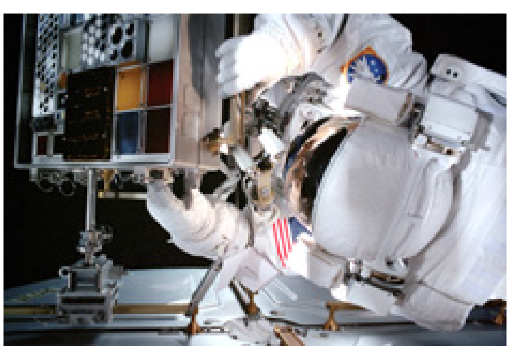
Specimen Number	Base Material	Marking Method	Marking Material	Encoded Info.	Planned Orbit Duration	Color of Mark	Pre Flight Grade	Marking Equipment
B-1-B9	Aluminum Plate	Laser Etching	N/A	123456	3 yrs.	Gray	A	Rofin-Sinar Nd:YAG Laser
B-2-E16-42	Aluminum	Dot Peen	N/A	2E1642	3 yrs.	White	A	Telesis TMP 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

IN ORBIT OBSERVATIONS

Shuttle Astronauts visited the MISSE experiments to make observations and to take photographs while MISSE 1 and 2 were in orbit. These Extra Vehicular Activities (EVA's) were made to the experiments in September, October and December of 2001; February, April and October 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.



Data Matrix Symbols Still Clearly Visible

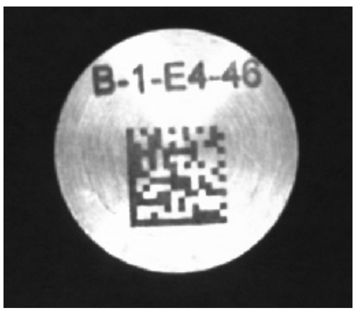


August 2003 EVA Photograph

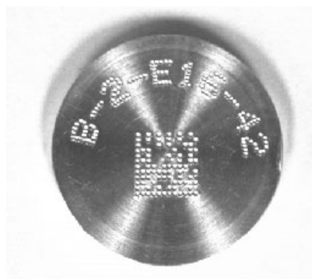
POST-FLIGHT GRADING

The flown MISSE 1 and 2 samples were evaluated under magnification and compared to the preflight photographs. Attempts were made to read the machine-readable symbols and where found to be readable, were graded in accordance with NASA-STD-6002 Revision A. The results of these evaluations and reading tests are recorded in Table 3 and discussed in the summary section.

Photographs Of Marked Coupons – After 4 Years in Low Earth Orbit

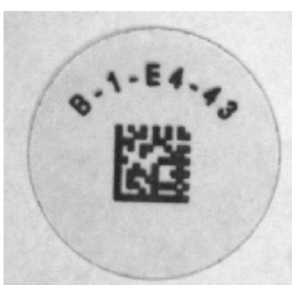


Elec. Chem Coloring
B-1-E4-46



Dot Peen
B-2-E16-42

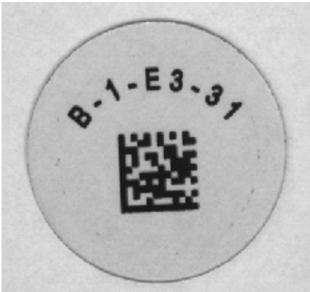
Laser Bonding
B-1-E4-42



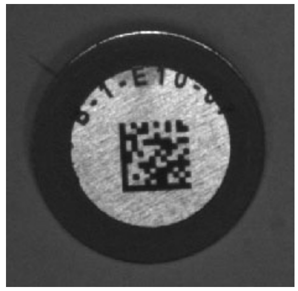
Laser Bonding on Glass
B-1-E4-43

Laser Coat & Remove
B-1-E4-44

GALE
B-1-E4-45



LIVD - Tin
B-1-E3-31



LIVD - Brass
B-1-E10-07

LIVD - Tin
B-2-E16-46

Table 3 – Pre-Flight/Post Flight Marking Comparison - MISSE 1 & 2

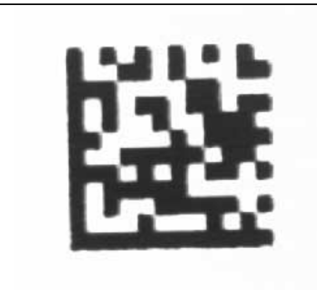
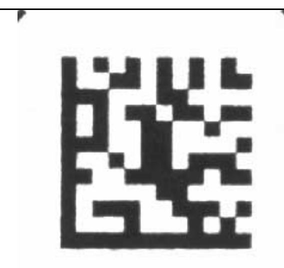
Sample Number	Marking Comparison			
	Pre Flight Mark Photograph	Pre Fight Verification Grade	Post Flight Mark Photograph	Post Fight Verification Grade
B-1-E3-27 LIVD - Brass	Line Pattern	**Good Contrast – Excellent Line Resolution**	Sample being Evaluated by Boeing Phantom Works	N/A
B-1-E3-28 LIVD - 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**

Table 3 – Pre-Flight/Post Flight Marking Comparison - MISSE 1 & 2

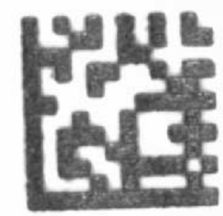
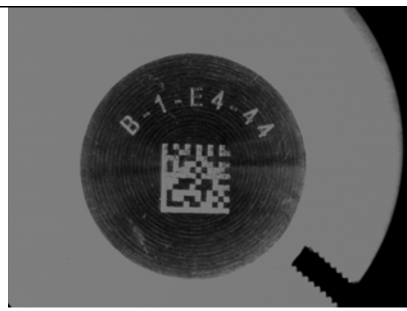
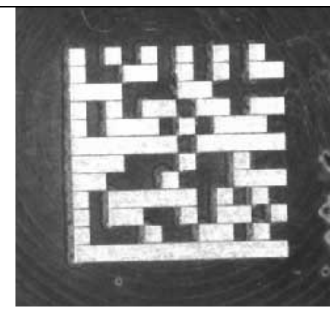
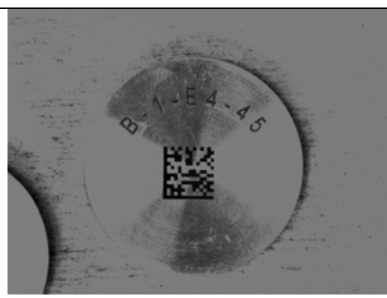
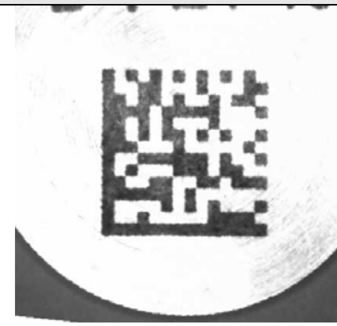
Sample Number	Marking Comparison			
	Pre Flight Mark Photograph	**Pre Fight Verification Grade**	**Post Flight Mark Photograph**	**Post Fight Verification Grade**
B-1-E4-43 Laser Bonding		**% Contrast A** **Axial Uniformity A** **Print Growth A** **Error Correction A** **Overall Grade A**		**% Contrast B** **Axial Uniformity A** **Print Growth A** **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**

Table 3 – Pre-Flight/Post Flight Marking Comparison - MISSE 1 & 2

Sample Number	Marking Comparison			
	Pre Flight Mark Photograph	Pre Fight Verification Grade	Post Flight Mark Photograph	Post Fight 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-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

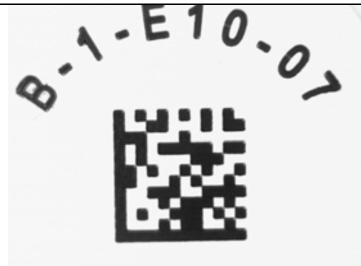
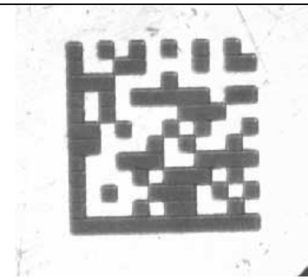
B-1-E10-07 LIVD - Brass		**% Contrast A** **Axial Uniformity A** **Print Growth B** **Error Correction A** **Overall Grade B**		**% Contrast B** **Axial Uniformity A** **Print Growth B** **Error Correction A** **Overall Grade B**

Table 3 – Pre-Flight/Post Flight Marking Comparison - MISSE 1 & 2

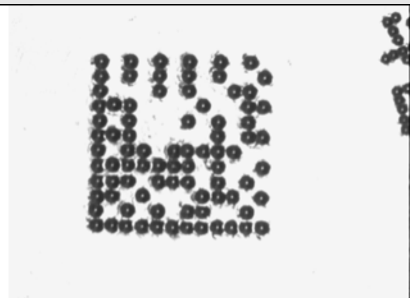
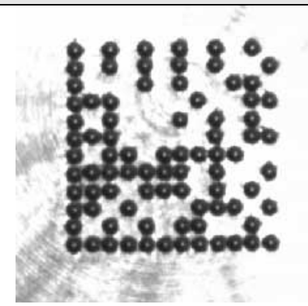
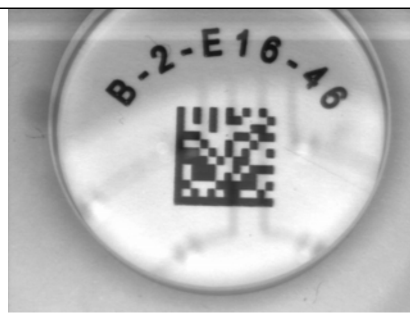
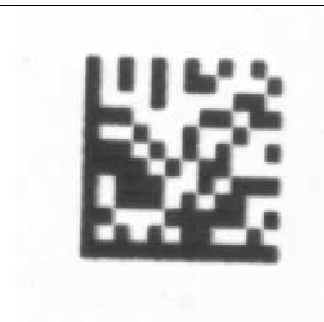
Sample Number	**Marking Comparison**			
	Pre Flight Mark Photograph	**Pre Fight Verification Grade**	**Post Flight Mark Photograph**	**Post Fight Verification Grade**
B-2-E16-42 Dot Peen		**% Contrast A** **Axial Uniformity A** **Print Growth A** **Error Correction A** **Overall Grade A**		**% Contrast A** **Axial Uniformity A** **Print Growth A** **Error Correction A** **Overall Grade A**
B-2-E16-43 LIVD Note: Position reassigned after marking. ID's as B-2-E16-46, flown in position B-2-E16-43		**% 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 4 – Pre-Flight/Post Flight Marking Comparison Continued – MISSE 3 and 4

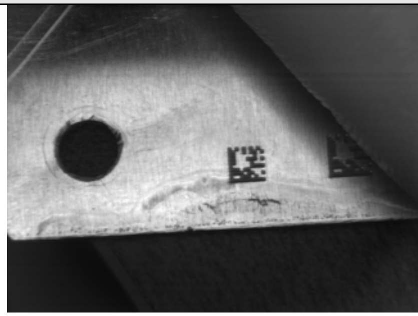
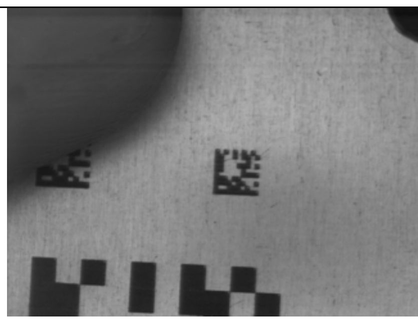
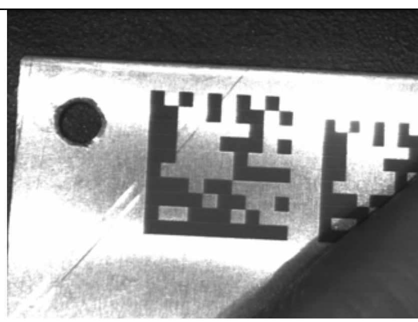
Sample Number	Marking Comparison			
	Pre Flight Mark Photograph	Pre Flight Verification Grade	Post Fight Mark Photograph	Post Fight Verification Grade
B-1-B9 Small - Bare Laser Etch Data Cell Size Study		**% Contrast A** **Axial Uniformity A** **Print Growth A** **Error Correction A** **Overall Grade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

Table 4 – Pre-Flight/Post Flight Marking Comparison Continued – MISSE 3 and 4

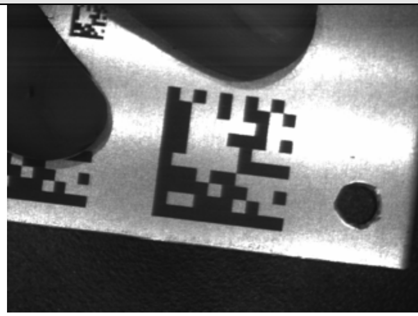
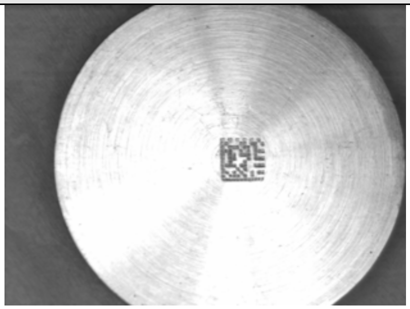
Sample Number	Marking Comparison			
	Pre Flight Mark Photograph	**Pre Flight Verification Grade**	**Post Fight Mark Photograph**	**Post Fight Verification Grade**
B-1-B9 Large - Anodized Laser Etch Data Cell Size Study		**% Contrast A** **Axial Uniformity A** **Print Growth A** **Error Correction A** **Overall Grade A**		
B-2-E16-43 Laser Etch		**% Contrast A** **Axial Uniformity A** **Print Growth A** **Error Correction A** **Overall Grade A**		
B-2-E16-44 LISI		**% Contrast A** **Axial Uniformity A** **Print Growth A** **Error Correction A** **Overall Grade A**		

Table 4 – Pre-Flight/Post Flight Marking Comparison Continued – MISSE 3 and 4

Sample Number	Marking Comparison			
	Pre Flight Mark Photograph	Pre Flight Verification Grade	Post Fight Mark Photograph	Post Fight Verification Grade
B-2-E16-45 Laser Shotpeen		**% Contrast A** **Axial Uniformity A** **Print Growth B** **Error Correction A** **Overall Grade B**		

SUMMARY

Siemens personal at the SRC marked two sets of samples to support this program. One set was retained at the SRC as control specimens and the second set was incorporated into MISSE 1 and 2, which were subsequently flown in earth orbit for four (4) years. A detail comparison was performed between these control specimens and flown specimens on October 11, 2005 and the following observations were made.

All of the Data Matrix symbols flown received passing grades as defined by International Standard Organization (ISO) document ISO-15415 as amended by NASA-STD-6002B. Only one (1) of the flown symbols showed signs of degradation. This was specimen number B-1-E4-43 (Laser Bonding marking process), which showed a slight decrease in contrast, falling from an A grade ($\geq$0.50 percent) to a B grade ($\geq$0.40 percent). This was attributed to a combination of exposure to strong UV light and atomic oxidation. The B grade is acceptable per the standard, which requires an A or B grade at point of manufacture and remarking in the field after the mark quality verification grade levels fall to a C grade.

The mark quality of specimen number B-1-E4-44 (Laser Coat and Remove – VAVD) improved over the 4 years in orbit. The contrast levels for this specimen increased as the copper colored coating darken to a dark green as a result of oxidation. This specimen was the only specimen to show signs of micro-partial 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 or on metal at time of coating. This contamination resulted in coating discoloration after exposure to the LEO environment.

The MISSE 1and 2 marking program exceeded all expectations and meet 100 percent of the SRC’s Principle Investigators objectives.

RECOMMENDATIONS

Based on the results of this experiment, Siemens recommends the following ground rules for in-orbit part identification marking:

1. Identify and test other Laser Coat and Discolor and Laser Coat and Remove materials and complementing substrate coloring and clear coat materials.

2. Require the use of matt finished clear coats in conjunction with Laser Bonding and Laser Coat and Remove marking processes.

3. Require that markings applied to glass substrates using Laser Inducted Vapor Deposition (LIVD) process be applied to the interior (unexposed) side of the item.

4. Replace the electro-chemical coloring (AC current) process tested as part of this experiment with a deep electro-chemical etch process (DC current) to form a recessed marking that is enhanced using a coloring agent to improve contrast. This marking, protected with a matte finished clear coat, will be more durable and easier to read.

5. Explore means to backfill dot peen markings to improve readability using hand-held readers.

6. Implement a Rocket Engine Marking Development and Test Program (high temperature applications). Spin off from this program would benefit the automotive, aircraft, pipe, catalytic converter and other commercial industries.

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1. D. L. Roxby, USAF Aging Landing Gear Life Extension Program Marking Test Report, March 29, 2001

2. Robert M. Beggs , U.S. Army Aviation Parts Marking Demonstration Final Report**,** September 7, 2001

3. Roxby, D. L.; USCG Flight Safety Critical Aircraft Parts Direct Part Marking (DPM) Verification Program Report, January 15, 2004

4. Coates, J.; USAF Landing Gear Life Extension Program Reports GA-C23527, GA-C24577, GA-C24578, GA-C24623, GA-C24624 and GA-C24688

5. Roxby, D. L.; National Center for Manufacturing Sciences (NCMS)/DoD Retrofit Parts Marking Project Final Report, September 30, 2004

6. MIL-STD-130**,** Identification Marking Of U.S. Military Property

7. NASA-STD-6002, Applying Data Matrix Identification Symbols On Aerospace Parts

8. NASA-HDBK-6003, Application Of Data Matrix Identification Symbols To Aerospace Parts Using Direct Part Marking Methods/Techniques

9. More information related to the MISSE 1 and 2 Experiments can be obtained on Web Site: http://misseone.larc.nasa.gov/