DISTRIBUTION A: Approved for public release; distribution is unlimited

RDECOM

TARDEC

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

Embedded NDE for Glass Armor

Sensor Enhanced Armor- Non-Destructive Evaluation Laboratory
Dr. Thomas Meitzler, thomas.j.meitzler.civ@mail.mil

Defense Working Ground on Non Destructive Testing , 5-9 December 2011

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
05 DEC 2011	**Technical Report**	**05-12-2011 to 05-12-2011**

4. TITLE AND SUBTITLE
EMBEDDED NON-DESTRUCTIVE EVALUATION FOR GLASS ARMOR

5a. CONTRACT NUMBER
5b. GRANT NUMBER
5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Thomas Meitzler

5d. PROJECT NUMBER
5e. TASK NUMBER
5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army TARDEC ,6501 E.11 Mile Rd,Warren,MI,48397-5000

8. PERFORMING ORGANIZATION REPORT NUMBER
#22465

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army TARDEC, 6501 E.11 Mile Rd, Warren, MI, 48397-5000

10. SPONSOR/MONITOR'S ACRONYM(S)
TARDEC

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
#22465

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
Submitted to Defense Working Ground on Non-Destructive Testing, 5-9 December 2011

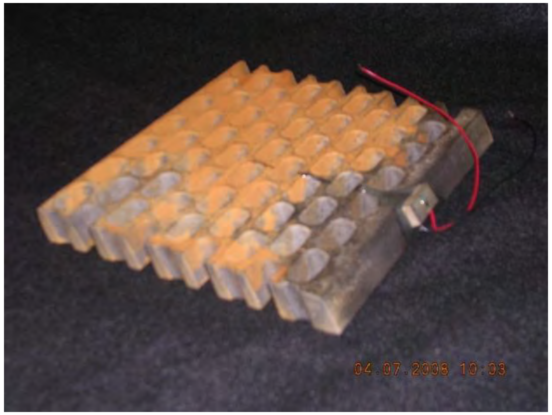
14. ABSTRACT
N/A

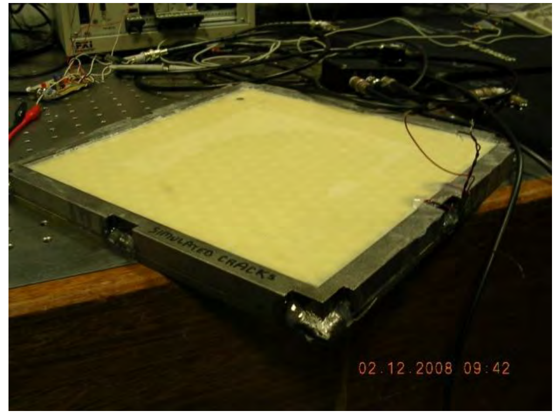
15. SUBJECT TERMS

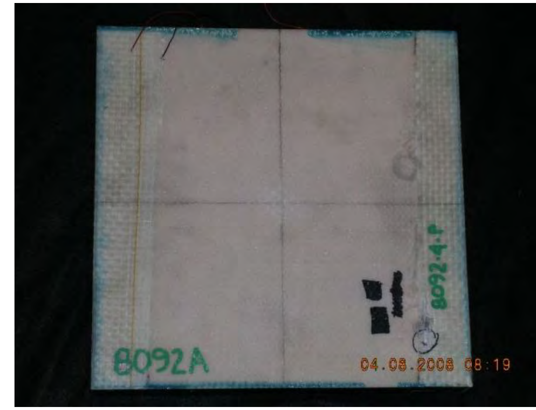
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**Same as Report (SAR)**	**20**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

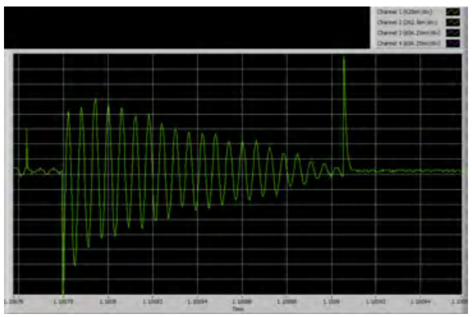
Armor Solutions Tested with Ultrasonics
NDT/E leading to Sensor Enhanced Armor

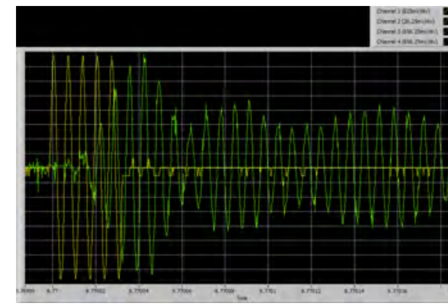




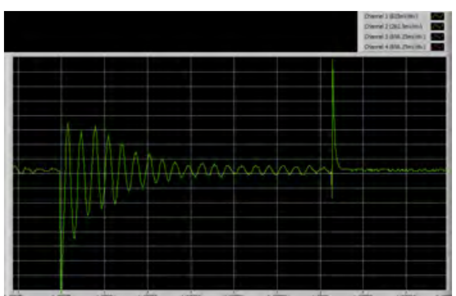


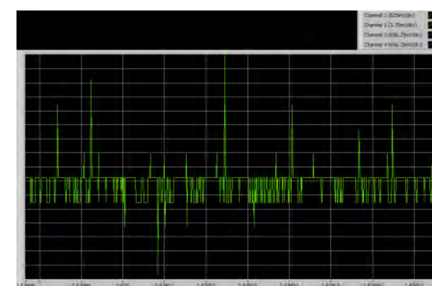
Undamaged





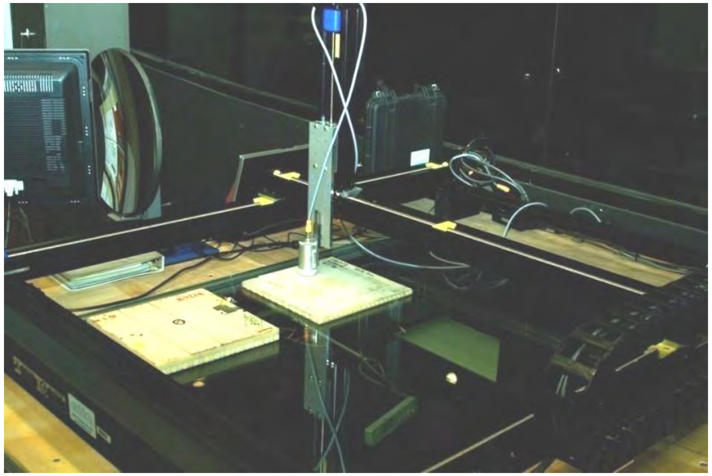
Damaged





There is a profound difference in the shape and amplitude of the echo signal between the damaged and undamaged plates. Tests are underway using embedded transducers for real-time armor integrity monitoring.

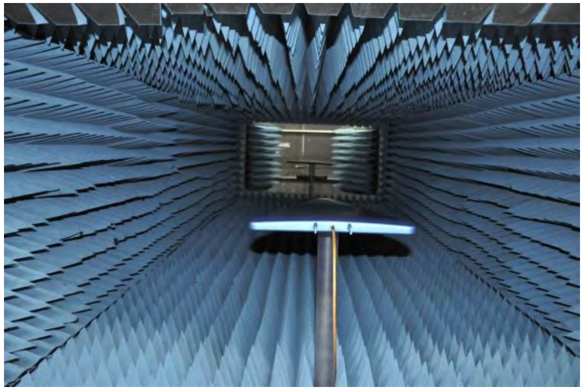
In House NDE and Electromagnetic Compatibility Capabilities



Millimeter wave Scanning Imager

Phased Array Ultrasound Immersion Tank

Low Energy X-ray

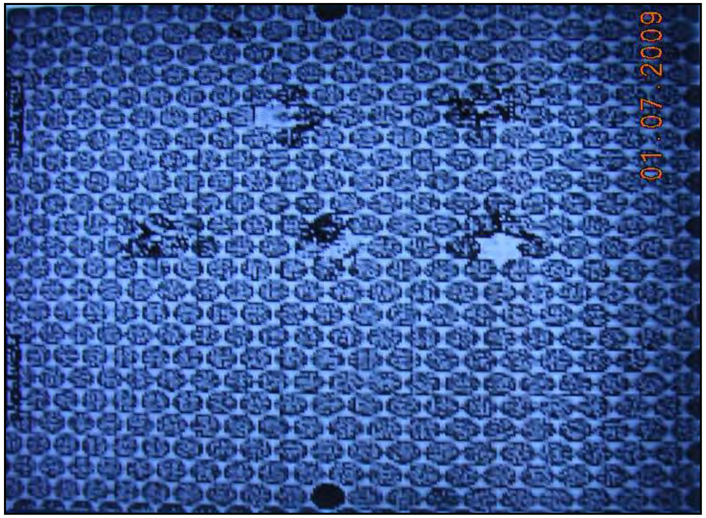


Anechoic Chamber

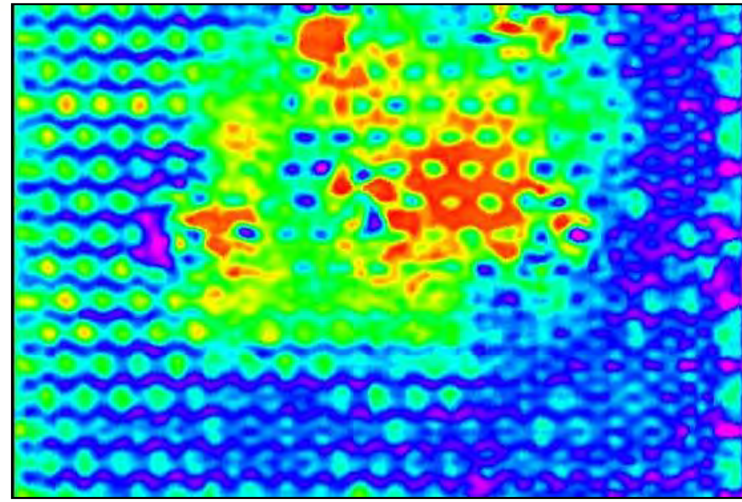
Thermal Imaging System

X-ray, microwave and ultrasound images of armor

Ceramic Pellet armor

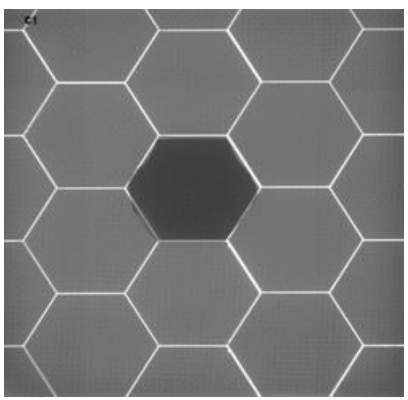


X-ray

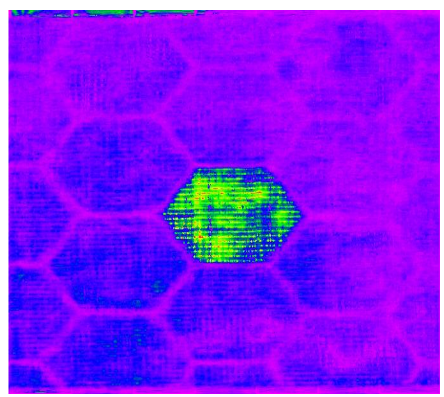


Microwave

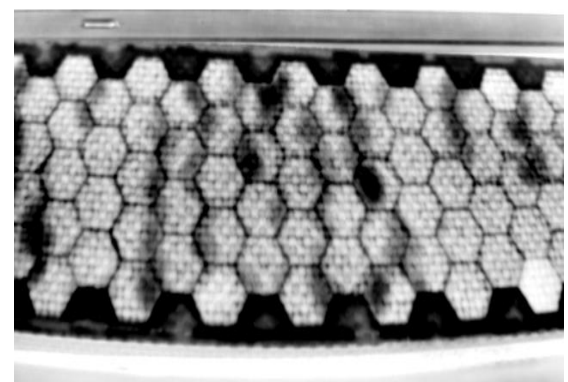
Ceramic Composite Armor



X-ray

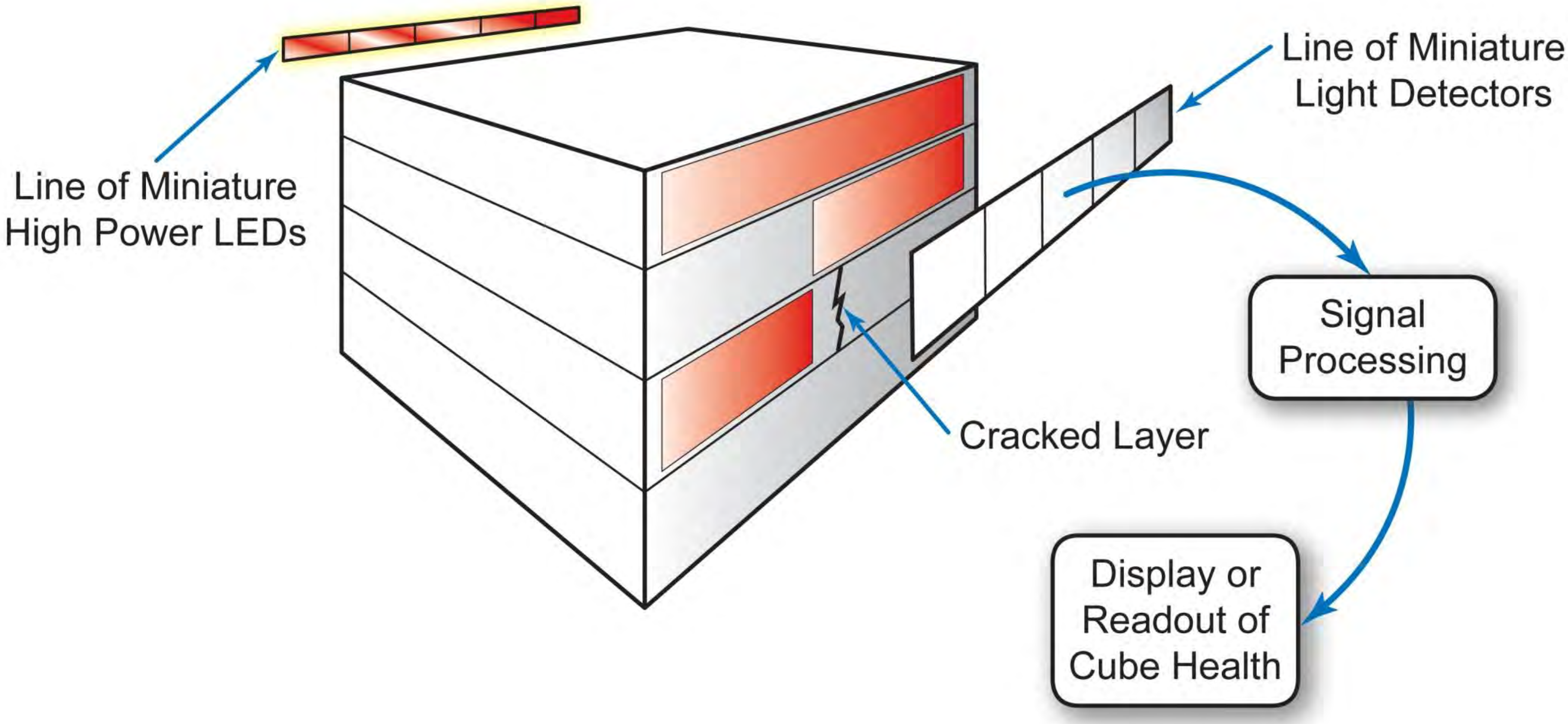


Ultrasound



Infrared

Health Monitoring of Glass Armor



Embedded glass armor NDE

• The U.S. Army has developed a new kind of armor protection for vehicles which consists of several glass plates. The plates are inserted in a plastic box and epoxy material is used to prevent the plates from being damaged by moving inside the box.

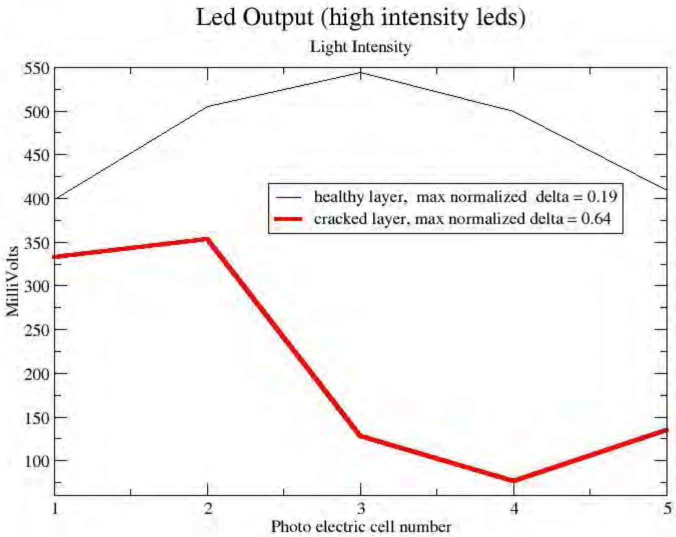
• To prevent the plates from chipping, the plastic box is encased in a steel box. The typical NDE procedure for this type of armor is to check for cracked plates using a high intensity X-ray machine. However the X-ray equipment is relatively expensive and usually not available in theater. Dismounting the cubes from the vehicle for the purpose of inspection is also inconvenient and quite labor intensive.

• We have developed a new method of NDE which is inexpensive, available everywhere (the testing apparatus is inside the cube) and the output is readily understandable.

Optical NDE for glass plates

The glass plates are transparent, and light is readily transmitted through them. Light waves that are transmitted from one side of a glass layer to the other are diffused and scattered if the layer has a crack and that the light fall-off changes drastically at the crack interfaces. LED's were used to illuminate the top two layers of the three glass layers of the opposite side. (The bottom layer is dark because it wasn't illuminated)

The light intensity is relatively uniform in the top layer; however in the second layer there is a sharp discontinuity in the light intensity in roughly the middle of the layer. (The second layer has a crack in it.) We measured the light output with photo transistors at five equidistant locations along the top two layers. Then we calculated the maximum change in slope in each layer.



Method Verification

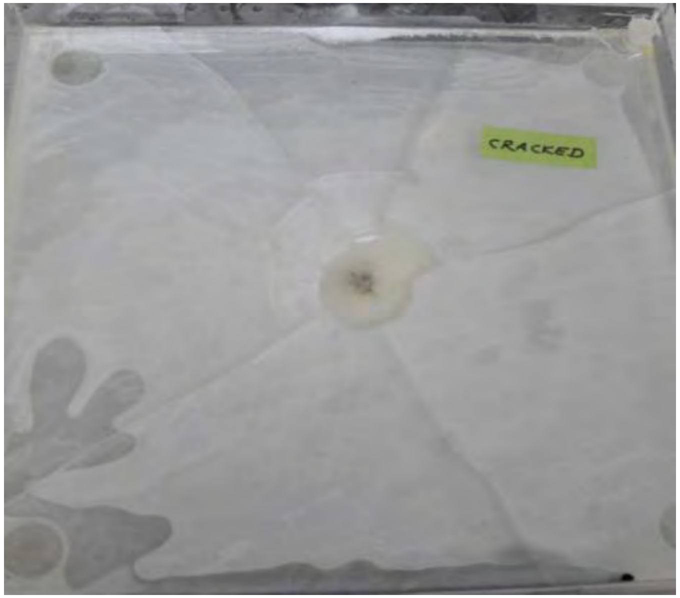
• One of the cubes was cracked using a bullet. Then the glass plates, the LED's and the photo transistors were placed inside a plastic box. An epoxy resin was used to prevent the contents of the box from moving .

•The differences in manufacturing variability in adding the resin caused the method to fail. The method wasn't sufficiently robust to accommodate slight variations in manufacturing. In order to overcome this difficulty we decided we needed to develop a new method which met the following criteria:
A method that is less sensitive to manufacturing variability in building the cube.

•Doesn't require strict manufacturing tolerances or an "ideal part".
•Requires very little data collection and computation.
•All computer components could fit in a 6 mm space which can be inserted between
• the armor plates and the plastic cube containing the armor plates. (The plastic cube
• is inserted inside a steel box in a later procedure).
•The method should be robust.
•The data analysis should be quick and easy to use and interpret.

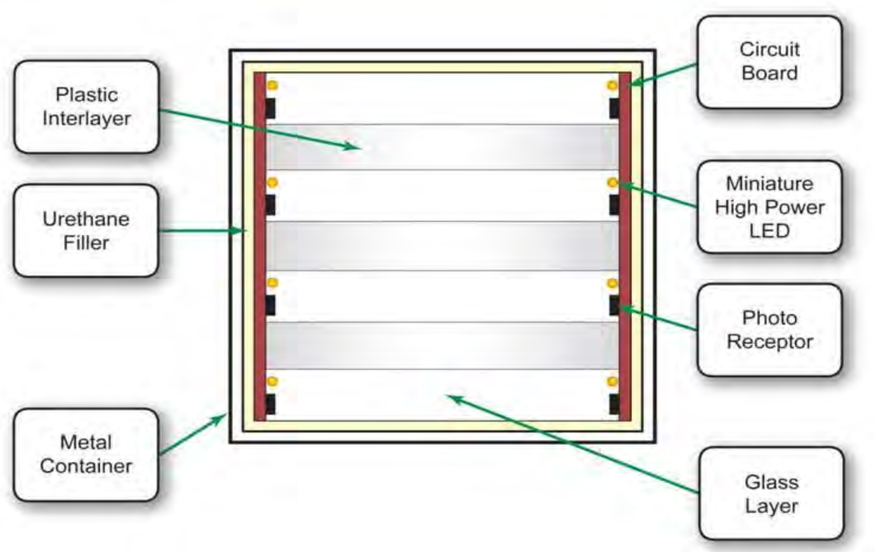
Glass Sample Images

Top View of a healthy Armor Sample



Top View of a damaged Armor Sample

Hardware



Glass cube

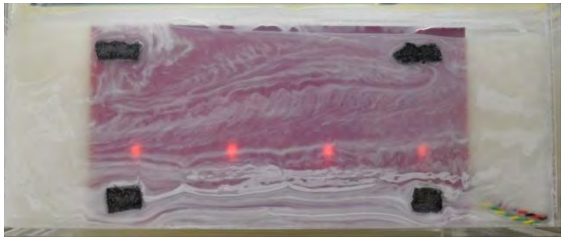
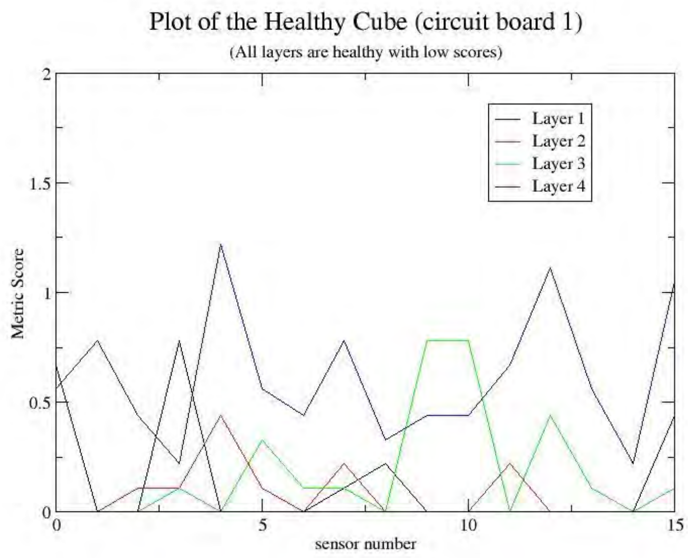
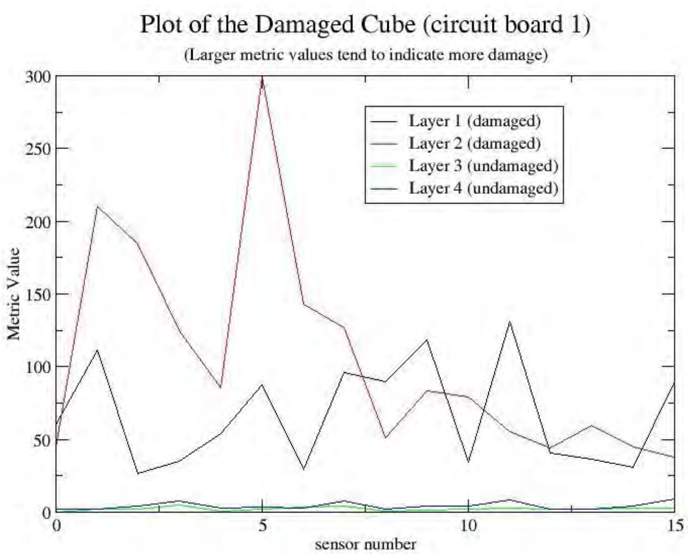


Image of the circuit board (side view)

Metric Evaluation





Results of Testing Two Cubes (one circuit board)
Cube 1 (before and after Damage)
Cube 2 (Two Repetitions) (

Cube 1 (before damage)

Layer Number	Metric Score
1	1.72
2	1.53
3	2.09
4	2.16

Cube 2 (trial 1)

Layer Number	Metric Score
1	0.89
2	0.56
3	0.67
4	1.22

Cube 1 (after damage)

Layer Number	Metric Score
1	205.88
2	299.74
3	4.35
4	5.35

Cube 2 (trial 2)

Layer Number	Metric Score
1	0.89
2	0.67
3	0.89
4	1.44

System Output

System Output from a Healthy Armor Cube

System Output from a Damaged Armor Cube

Conclusions

•An embedded, nondestructive apparatus and methodology has been developed for armor composed of glass layers.

•The method and apparatus (patent pending) was developed because the only previous method of inspection required the use of a high power X-ray machine.

•The method presented uses off the shelf components and a rather simple algorithm which doesn't require extensive computation. LED's are used for light generation and photo transistors to measure the amount of light transmitted.

•The apparatus is installed when the armor is manufactured before it is encased in a steel box. The system output is presented in a simple easy to use format which tells the user if the armor cube is healthy or damaged. If damage has occurred, the user is informed of which layers in the cube are damaged.

Other past collaborations

NASA/ RDECOM-TARDEC Space Act Agreement

- Mutually beneficial research agreement between NASA-Kennedy Space Center (KSC) and US Army TARDEC (SOW entitled: “Ice/Frost Detection and Evaluation”) signed 21 January 2004

- NASA benefits: multi-spectrum sensor analysis and research for ice detection and orbiter tile evaluation

- Army benefits: applications to ice detection for wing/rotary aircraft and vehicle remote damage assessment

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

Unclassified

Space Shuttle Anatomy Basics

- **The Space Shuttle is comprised of 3 main components: orbiter, External Tank (ET), and 2 SRBs**
- **Two SRB's provide 80% of the thrust to launch the vehicle (jettisoned after 2 min., 28 naut. miles altitude - recovered)**
- **The ET houses liquid cryogenic propellant to supply the orbiter's 3 main engines (ET jettisoned after 8½ minutes, 70 miles altitude - not recovered)**
- **The ET is constructed of Aluminum and is 154 ft. long, 28 ft. diameter**
- **The outer Al surface is covered with thermal Spray-On Foam Insulation (SOFI)**
- **The ET acts as the "backbone" of the shuttle system during launch supporting SRB and orbiter thrust loads of 7.8 million lbs**

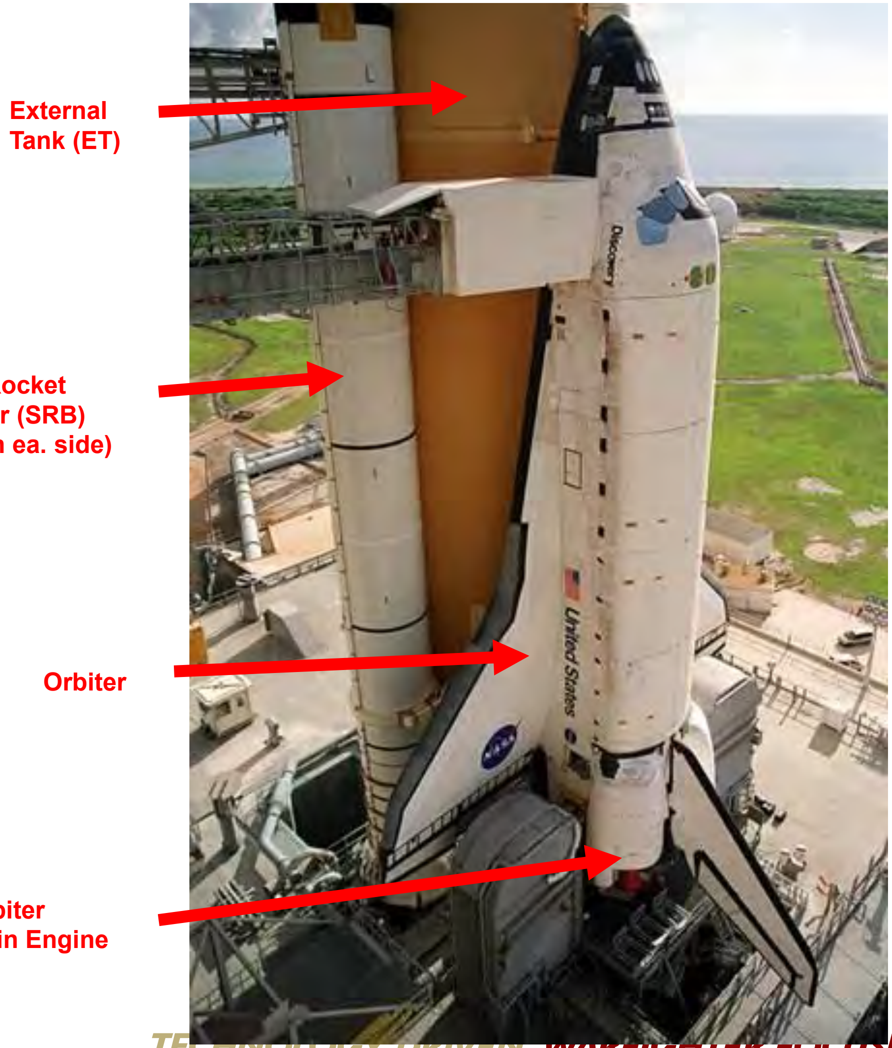
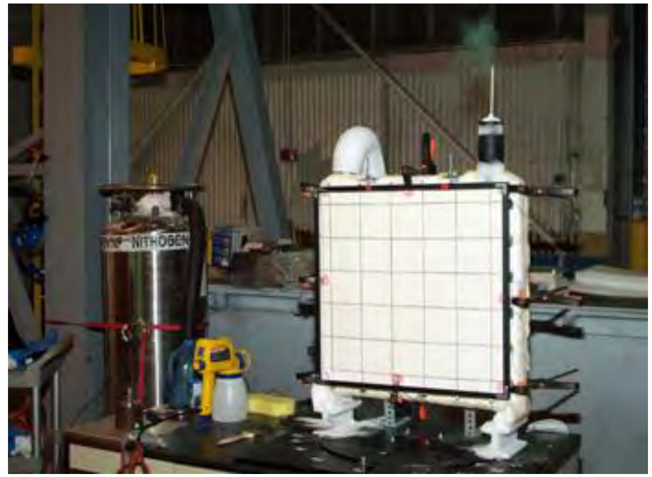


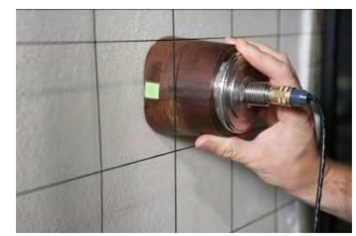
Photo courtesy of NASA

NASA Ice Detection System
Visual Perception Team Collaborative Work with NASA & MDA Robotics

SANG Testing Facility and Experimental Setup



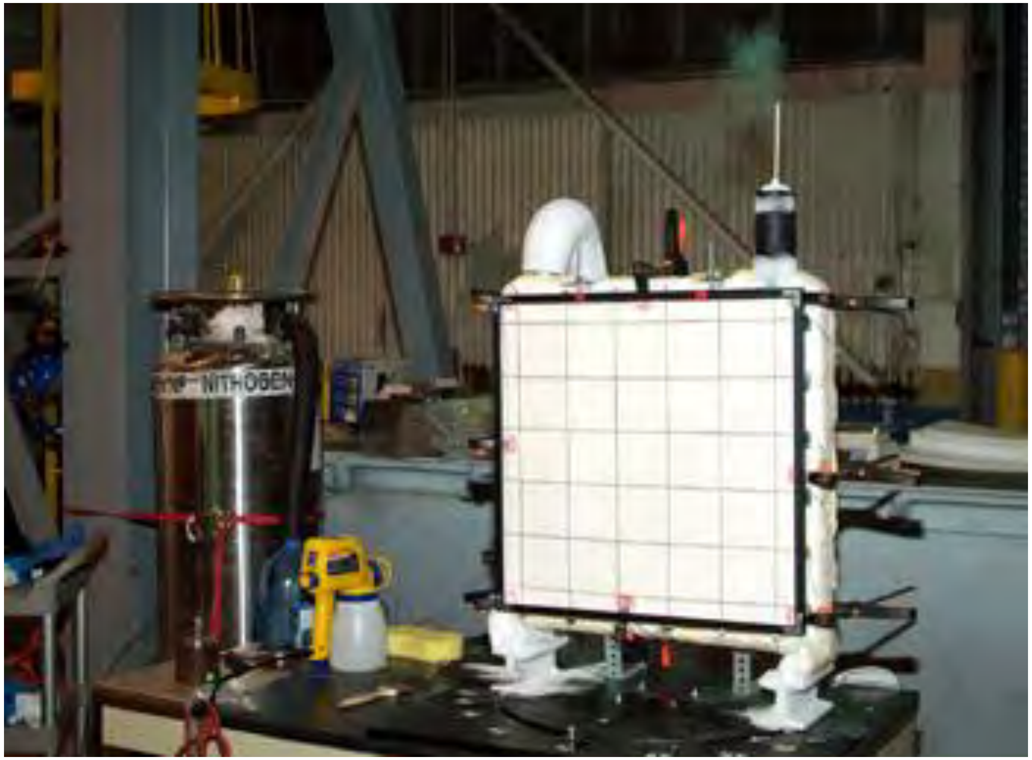
Experimental Setup of SOFI panel and LN2 cryogen



Kaman eddy current sensor.
Used by TARDEC scientists to measure the ice thickness on the SOFI panel.

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

SOFI Panel for Ice Buildup and Camera Imaging



Grid used to demarcate areas for imaging and removed actual during imaging with MDA camera.

Panel on lazy susan platform for varying the angle.

SOFI panel mounted on Cryogenic panel prepared by NASA KSC Applied Physics Lab

The MDA System

- Prototype was developed in about six months
- Portable cart (battery powered) unit weighs about 200 lbs
- Positive N2 pressurized components for use on launch pad (to isolate electronics from LO2 propellant)
- On-board computer and color LCD display
- On-board VCR to record video
- Range of use from 25-75 feet
- Uses a Xenon strobe light (<30W) but was approved for launch pad use (existing Xenon lighting is used on pad)
- Un-cooled focal plane array sensor

MDA prototype

RDECOM

Cont. of Testing MDA Ice Detection System

TARDEC

MDA System LCD Ice Measurement Display

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.