# Non-Destructive Evaluation of Full-Size Photovoltaic Modules

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## Abstract

The size and construction of modern PV modules present challenges to the identification and characterization of manufacturing defects and field failures. These challenges are similar to those presented to the aerospace industry. The NDT group at Sandia specializes in these types of measurements. Relevant capabilities include Computed Tomography, Ultrasonic Diagnostics and Pulsed Thermography.

## Challenges

- Full size PV modules are too large to fit in most common laboratory inspection instruments.
- Packaging of PV modules – inherently designed to withstand 25 years or more of field deployment – make extraction of smaller samples difficult or impossible without creating additional damage.
- Sectioning of PV modules to find failures becomes a “needle in a haystack” exercise if the location of the failure is not known a priori.
- Techniques such as Electroluminescence and Lock-in Infrared Thermography are commonly used, but these techniques rely on current injection into the module and are best suited to the identification of cell failures.

## Similarities to the Aerospace Industry

- Components to be inspected have high surface area and are thin.
- Inspection necessarily cannot introduce additional damage.
- Increasingly, fuselages are made of inhomogeneous composite materials.
- Considerable investment has been made in developing Non-Destructive Testing (NDT) techniques that are rapid, accurate and portable.

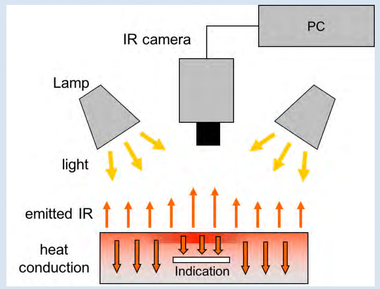
## Proposed Approach

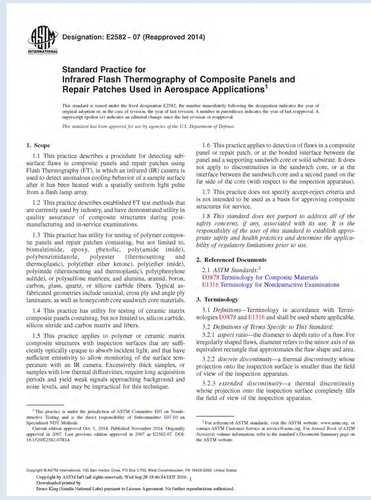
- Evaluate each capability to the investigation of defects/failures within PV modules.
- Candidate inspection techniques will be evaluated for their effectiveness and where necessary, adapted with new software/analysis techniques.
- Known failed modules will be compared to known good modules to establish Probability of Detection guidelines.
- Modules will be sourced from existing DOE funded projects such as Predicts II and partnerships with commercial and utility scale system owners/operators.
- Once established, characterization techniques will be made available to other DuraMat capability areas and industry stakeholders.

## Example Capabilities

### Thermography

- A brief pulse of light is applied to the target
- High frequency IR imaging allows the thermal wave to be observed as it moves through the target
- Internal flaws such as debonding, voids or inhomogeneous materials impede the thermal wave, creating thermal contrast.
- Can be applied in the field



Designation: E2582 – 07 (Reapproved 2014)

Standard Practice for
Infrared Flash Thermography of Composite Panels and Repair Patches Used in Aerospace Applications[1]

This standard is issued under the fixed designation E2582; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

*This standard has been approved for use by agencies of the U.S. Department of Defense.*

1. Scope

1.1 This practice describes a procedure for detecting subsurface flaws in composite panels and repair patches using Flash Thermography (FT), in which an infrared (IR) camera is used to detect anomalous cooling behavior of a sample surface after it has been heated with a spatially uniform light pulse from a flash lamp array.

1.2 This practice describes established FT test methods that are currently used by industry, and have demonstrated utility in quality assurance of composite structures during post-manufacturing and in-service examinations.

1.3 This practice has utility for testing of polymer composite panels and repair patches containing, but not limited to, bismaleimide, epoxy, phenolic, polyamide imide), polybenzimidazole, polyester (thermosetting and thermoplastic), polyether ether ketone), polyether imide), polyimide (thermosetting and thermoplastic), polyphenylene sulfide), or polysulfone matrices, and alumina, aramid, boron, carbon, glass, quartz, or silicon carbide fibers. Typical as-fabricated geometries include uniaxial, cross ply and angle ply laminates, as well as honeycomb core sandwich core materials.

1.4 This practice has utility for testing of ceramic matrix composite panels containing, but not limited to, silicon carbide, silicon nitride and carbon matrix and fibers.

1.5 This practice applies to polymer or ceramic matrix composite structures with inspection surfaces that are sufficiently optically opaque to absorb incident light, and that have sufficient emissivity to allow monitoring of the surface temperature with an IR camera. Excessively thick samples, or samples with low thermal diffusivities, require long acquisition periods and yield weak signals approaching background and noise levels, and may be impractical for this technique.

1.6 This practice applies to detection of flaws in a composite panel or repair patch, or at the bonded interface between the panel and a supporting sandwich core or solid substrate. It does not apply to discontinuities in the sandwich core, or at the interface between the sandwich core and a second panel on the far side of the core (with respect to the inspection apparatus).

1.7 This practice does not specify accept-reject criteria and is not intended to be used as a basis for approving composite structures for service.

1.8 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]
D3878 Terminology for Composite Materials
E1316 Terminology for Nondestructive Examinations

3. Terminology

3.1 *Definitions*—Terminology in accordance with Terminologies D3878 and E1316 and shall be used where applicable.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *aspect ratio*—the diameter to depth ratio of a flaw. For irregularly shaped flaws, diameter refers to the minor axis of an equivalent rectangle that approximates the flaw shape and area.

3.2.2 *discrete discontinuity*—a thermal discontinuity whose projection onto the inspection surface is smaller than the field of view of the inspection apparatus.

3.2.3 *extended discontinuity*—a thermal discontinuity whose projection onto the inspection surface completely fills the field of view of the inspection apparatus.

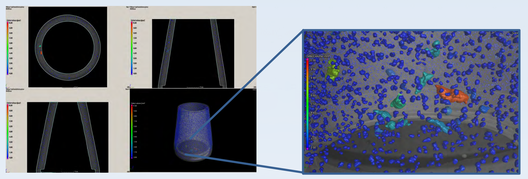
[1] This practice is under the jurisdiction of ASTM Committee E07 on Nondestructive Testing and is the direct responsibility of Subcommittee E07.10 on Specialized NDT Methods.
Current edition approved Oct. 1, 2014. Published November 2014. Originally approved in 2007. Last previous edition approved in 2007 as E2582-07. DOI: 10.1520/E2582-07R14.

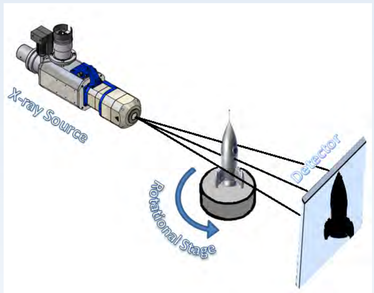
[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

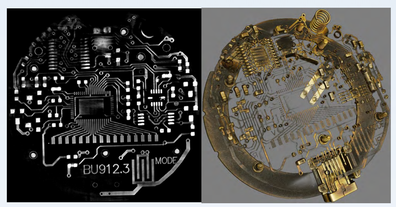


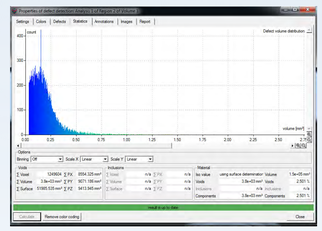
### Computed Tomography

- Computerized reconstruction of 2D X-Ray images to create a 3D representation of an object.





Designation: E2662 – 15

Standard Practice for
Radiographic Examination of Flat Panel Composites and Sandwich Core Materials Used in Aerospace Applications[1]

This standard is issued under the fixed designation E2662; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

*This standard has been approved for use by agencies of the U.S. Department of Defense.*

1. Scope*

1.1 This practice is intended to be used as a supplement to Practices E1742, E1255, E2033, and E2698.

1.2 This practice describes procedures for radiographic examination of flat panel composites and sandwich core materials made entirely or in part from fiber-reinforced polymer matrix composites. Radiographic examination is: *a*) Film Radiography (RT), *b*) Computed Radiography (CR) with Imaging Plate, *c*) Digital Radiography (DR) with Digital Detector Array's (DDA's), and *d*) Radioscopic (RTR) Real Time Radiography with a detection system such as an Image Intensifier. The composite materials under consideration typically contain continuous high modulus fibers (> 20 Gpa), such as those listed in 1.4.

1.3 This practice describes established radiographic examination methods that are currently used by industry that have demonstrated utility in quality assurance of flat panel composites and sandwich core materials during product process design and optimization, process control, after manufacture inspection, in service examination, and health monitoring. Additional guidance can be found in E2533, Guide for Nondestructive Testing of Polymer Matrix Composites Used in Aerospace.

1.4 This practice has utility for examination of flat panel composites and sandwich constructions containing, but not limited to, bismaleimide, epoxy, phenolic, polyamide imide), polybenzimidazole, polyester (thermosetting and thermoplastic), polyether ether ketone), polyether imide), polyimide (thermosetting and thermoplastic), polyphenylene sulfide), or polysulfone matrices; and alumina, aramid, boron, carbon, glass, quartz, or silicon carbide fibers. Typical as-fabricated geometries include uniaxial, cross ply and angle ply laminates; as well as honeycomb core sandwich constructions.

1.5 This practice does not specify accept-reject criteria and is not intended to be used as a means for approving flat panel composites or sandwich core materials for service.

1.6 To ensure proper use of the referenced standards, there are recognized nondestructive testing (NDT) specialists that are certified according to industry and company NDT specifications. It is recommended that a NDT specialist be a part of any composite component design, quality assurance, in service maintenance or damage examination.

1.7 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]
C274 Terminology of Structural Sandwich Constructions
D1434 Test Method for Determining Gas Permeability Characteristics of Plastic Film and Sheeting
D3878 Terminology for Composite Materials
E94 Guide for Radiographic Examination
E543 Specification for Agencies Performing Nondestructive Testing
E747 Practice for Design, Manufacture and Material Grouping Classification of Wire Image Quality Indicators (IQI) Used for Radiology
E1000 Guide for Radioscopy
E1025 Practice for Design, Manufacture, and Material Grouping Classification of Hole-Type Image Quality Indicators (IQI) Used for Radiology
E1165 Test Method for Measurement of Focal Spots of Industrial X-Ray Tubes by Pinhole Imaging
E1255 Practice for Radioscopy
E1309 Guide for Identification of Fiber-Reinforced Polymer-Matrix Composite Materials in Databases

[1] This practice is under the jurisdiction of ASTM Committee E07 on Nondestructive Testing and is the direct responsibility of Subcommittee E07.06 on Radiology (X and Gamma) Method.
Current edition approved June 15, 2015. Published July 2015. Originally approved in 2009. Last previous edition approved in 2009 as E2662-09. DOI: 10.1520/E2662-15.

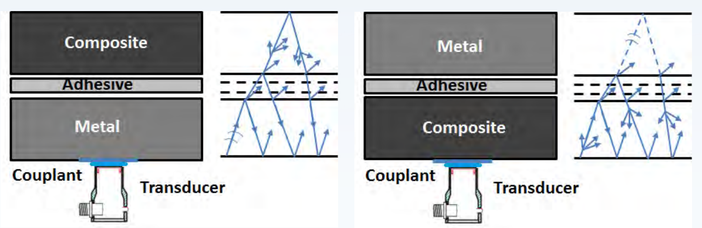
[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

*A Summary of Changes section appears at the end of this standard



### Ultrasonic Diagnostics

- Ultrasonic sound waves are injected into a sample via a transducer and a coupling agent (often water or a gel)
- When the sound hits a boundary, it will either be reflected back toward the source or scattered.
- Strong bonds at material interfaces allow the wave to continue to propagate.
- Defects within a material are detected by the change in wave propagation (reflected or transmitted).
- Various methods are available, including direct contact, immersion and array.
- Some methods can be applied in the field.




Designation: E2580 – 12

Standard Practice for
Ultrasonic Testing of Flat Panel Composites and Sandwich Core Materials Used in Aerospace Applications[1]

This standard is issued under the fixed designation E2580; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

*This standard has been approved for use by agencies of the U.S. Department of Defense.*

1. Scope*

1.1 This practice establishes two procedures for ultrasonic testing (UT) of flat panel composites and flat sandwich core panels (solid surfaces). Typical as-fabricated lay-ups include uniaxial, cross ply and angle ply laminates as well as honeycomb sandwich core materials. These procedures can be used throughout the life cycle of the materials; product and process design optimization, on line process control, after manufacture inspection, and in service inspection. Contact methods such as angle-beam techniques using shear waves, or surface-borne techniques using Lamb waves, are not discussed.

1.2 Ultrasonic testing is a common sub surface method for detection of laminar oriented discontinuities. Two techniques can be considered based on panel surface accessibility; pulse echo for one sided and through transmission (bubbler/squirter) for two sided. As used in this practice, both require the use of a pulsed straight-beam ultrasonic longitudinal wave followed by observing indications of either the reflected (pulse-echo) or received (through transmission) wave. The general types of anomalies detected by both techniques include foreign materials, delamination, disbond/un-bond, fiber debonding, inclusions, porosity, and voids.

1.3 This practice provides two ultrasonic test procedures. Each has its own merits and requirements for inspection and shall be selected as agreed upon in a contractual document.

1.3.1 *Test Procedure A, Pulse Echo (non-contacting and contacting)*, is at a minimum a single transducer transmitting and receiving a longitudinal wave in the range of 0.5 to 20 MHz (see Fig. 1). This procedure requires access to only one side of the specimen. This procedure can be conducted by automated or manual means. Automated and manual test results may be imaged or recorded.

1.3.2 *Test Procedure B, Through Transmission*, is a combination of two transducers. One transmits a longitudinal wave and the other receives the longitudinal wave in the range of 0.5 MHz to 20 MHz (see Fig. 2). This procedure requires access to both sides of the specimen. This procedure is automated and the examination results are recorded.

1.4 This practice does not specify accept-reject criteria.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]
C274 Terminology of Structural Sandwich Constructions
D3878 Terminology for Composite Materials
D5655/D5655M Guide for Preparation of Flat Composite Panels with Processing Guidelines for Specimen Preparation
E114 Practice for Ultrasonic Pulse-Echo Straight-Beam Contact Testing
E543 Specification for Agencies Performing Nondestructive Testing
E1309 Guide for Identification of Fiber-Reinforced Polymer-Matrix Composite Materials in Databases
E1316 Terminology for Nondestructive Examinations
E1434 Guide for Recording Mechanical Test Data of Fiber-Reinforced Composite Materials in Databases
E1471 Guide for Identification of Fibers, Fillers, and Core Materials in Computerized Material Property Databases
2.2 *SAE Standards:*[3]
ARP 5658 Solid Composite Laminate NDI Reference Standards, Issued 2001-09
ARP 5659 Composite Honeycomb NDI Reference Standards, Issued 2001-09

[1] This practice is under the jurisdiction of ASTM Committee E07 on Nondestructive Testing and is the direct responsibility of Subcommittee E07.06 on Ultrasonic Method.
Current edition approved June 15, 2012. Published July 2012. Originally approved in 2009. Last previous edition approved in 2007 as E2580–07. DOI: 10.1520/E2580-12.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from Society of Automotive Engineers (SAE), 400 Commonwealth Dr., Warrendale, PA 15096-0001, http://www.sae.org.

*A Summary of Changes section appears at the end of this standard



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