

NASA/CR-2013-218043



LSP Composite Substrate Destructive Evaluation Test Assessment Manual

*Daniel J. Kovach and Grant J. Erickson
The Boeing Company, Seattle, Washington*

November 2013

NASA STI Program . . . in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA scientific and technical information (STI) program plays a key part in helping NASA maintain this important role.

The NASA STI program operates under the auspices of the Agency Chief Information Officer. It collects, organizes, provides for archiving, and disseminates NASA's STI. The NASA STI program provides access to the NASA Aeronautics and Space Database and its public interface, the NASA Technical Report Server, thus providing one of the largest collections of aeronautical and space science STI in the world. Results are published in both non-NASA channels and by NASA in the NASA STI Report Series, which includes the following report types:

- **TECHNICAL PUBLICATION.** Reports of completed research or a major significant phase of research that present the results of NASA Programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA counterpart of peer-reviewed formal professional papers, but having less stringent limitations on manuscript length and extent of graphic presentations.
- **TECHNICAL MEMORANDUM.** Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.
- **CONTRACTOR REPORT.** Scientific and technical findings by NASA-sponsored contractors and grantees.

- **CONFERENCE PUBLICATION.** Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or co-sponsored by NASA.
- **SPECIAL PUBLICATION.** Scientific, technical, or historical information from NASA programs, projects, and missions, often concerned with subjects having substantial public interest.
- **TECHNICAL TRANSLATION.** English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services also include organizing and publishing research results, distributing specialized research announcements and feeds, providing information desk and personal search support, and enabling data exchange services.

For more information about the NASA STI program, see the following:

- Access the NASA STI program home page at <http://www.sti.nasa.gov>
- E-mail your question to help@sti.nasa.gov
- Fax your question to the NASA STI Information Desk at 443-757-5803
- Phone the NASA STI Information Desk at 443-757-5802
- Write to:
STI Information Desk
NASA Center for AeroSpace Information
7115 Standard Drive
Hanover, MD 21076-1320

NASA/CR–2013-218043



LSP Composite Substrate Destructive Evaluation Test Assessment Manual

*Daniel J. Kovach and Grant J. Erickson
The Boeing Company, Seattle, Washington*

National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23681-2199

Prepared for Langley Research Center
under Contract NNL10AA05B

November 2013

The use of trademarks or names of manufacturers in this report is for accurate reporting and does not constitute an official endorsement, either expressed or implied, of such products or manufacturers by the National Aeronautics and Space Administration.

Available from:

NASA Center for AeroSpace Information
7115 Standard Drive
Hanover, MD 21076-1320
443-757-5802

Contents

FOREWORD	III
1 SCOPE	1
1.1 PURPOSE.....	1
1.2 BACKGROUND	1
1.3 DAMAGE PROTECTION PERFORMANCE DATA FOR PANEL CONFIGURATIONS	2
2 REFERENCES	3
2.1 APPLICABLE DOCUMENTS.....	3
2.2 NOMENCLATURE.....	3
3 POST-TEST INSPECTIONS/EVALUATIONS	4
3.1 NON-DESTRUCTIVE DAMAGE AREA ASSESSMENTS	5
3.2 DESTRUCTIVE DAMAGE ASSESSMENTS	6
4 DELIVERABLES	8

THIS PAGE INTENTIONALLY LEFT BLANK

FOREWORD

The information described in this report was authored by Dan Kovach and Grant Erickson.

The authors would like to acknowledge the contributions and support of Patrice Ackerman.

1 SCOPE

This document provides standalone information for the Post-test Destructive Evaluation of composite panels manufactured to NASA Document DOC-128694, reference 2.1.1 and tested per NASA Document DOC-128696, Reference 2.1.3.

1.1 Purpose

This document defines the post-test non-destructive and destructive evaluations of Carbon Fiber Reinforced Plastic (CFRP) test panels for the purpose of evaluating the protection capabilities of Lightning Strike Protection (LSP) materials developed by the Aerospace Industry. The lightning direct effects test described in Reference 2.1.3 of the test articles described in Reference 2.1.1 provides a common baseline for correlation and comparison between LSP datasets. This will permit technically meaningful comparisons between different material types submitted by different manufacturers when tested by a capable vendor according to this test procedure. A simulated lightning strike on a CFRP panel is expected to produce ablation and delamination damage, both through the thickness of the panel and across the panel surface area. That damage will be evaluated per instructions in this document

1.2 Background

The growing application of composite materials in commercial aircraft manufacturing has increased the risk of aircraft damage from lightning strikes. With this growth in composite usage, new technical challenges arise. Composite skinned aircraft are more vulnerable to damage from lightning strikes than their aluminum skinned predecessors and new mitigation strategies and engineering practices are required to maintain the same level of safety and protection as achieved by aluminum skinned aircraft. The electrical current incident on an aircraft from a typical lightning strike can exceed 200,000 amperes, occurring in a fraction of a second. Without proper lightning strike protection, carbon fiber/epoxy and dielectric composites can be significantly damaged, particularly at the entry and exit points of the strike. Approaches have been developed to protect the composite structures from lightning direct effects to reduce damage to acceptable levels by using conductive foils or meshes in the outer layer of the composite system.

When a lightning strike occurs, the points of attachment and detachment on the aircraft surface must be found by visual inspection, and then assessed for

damage by maintenance personnel to ensure continued safe flight operations. Repairs may be required to replace damaged composite sections per Federal Aviation Administration (FAA) procedures if the damage exceeds the allowable damage limits for the structure.

Lightning test standard waveforms are simplified laboratory-generated waveforms that represent key lightning parameters including peak current, total energy transferred and signal rise and fall times. These statistical lightning environments are specified in the Society of Automotive Engineers (SAE) standard, Reference 2.1.4. To ensure flight safety, LSP studies are conducted for flight safety air-worthiness standards testing and to gain FAA certification. However, differences in preparation of test articles as well as variability in test procedures and practices between independent LSP studies have made it difficult to compare and contrast performance differences between different LSP data sets. A LSP Composite Substrate Lightning Test Operations Manual, reference 2.1.3, has been prepared to ensure consistency in future lightning strike protection evaluations to allow performance correlations across data sets.

This document specifies the processes to perform post-strike destructive damage evaluation of tested CFRP panels. It is recognized that many factors besides lightning damage protection are involved in the selection of an appropriate LSP for a particular system (e.g., cost, weight, corrosion resistance, shielding effectiveness, etc). This document strives primarily to address the standardized generation of damage protection performance data.

1.3 Damage Protection Performance Data for Panel Configurations

The NASA Aviation Safety Program supports research directed to ensure that future composite aircraft will survive lightning prone environments to safely navigate the National Air Space. Research to detect and mitigate lightning damage on composite aircraft is contained in the Atmospheric Environmental Safety Technology project managed at NASA Glenn Research Center, which includes a NASA Langley-led subproject titled Atmospheric Hazard Safety Mitigation led by Robert Neece. Project milestone AEST4.4.37 (Atmospheric Environment Safety Technologies) provides the funding mechanism for the development of this document. Additionally, it is the intention of the AEST program to manufacture and inspect test panels, both protected and unprotected, according to the document cited in section 2.1.1. Note that the pre-test Nondestructive Inspection (NDI) requirements for these panels are contained in reference 2.1.2. Following manufacture and inspection, these

panels will be subject to simulated strikes per the procedure identified in reference 2.1.3. Following test, it is intended for the panels to be qualitatively and quantitatively evaluated for their response, using the guidelines and procedures identified in this document.

Parties interested in acquiring a copy of these documents and the data generated from this test effort are invited to contact the AEST Task Monitor, George Szatkowski, at his email address (george.n.szatkowski@nasa.gov) or phone number (757-846-6149).

2 REFERENCES

2.1 Applicable Documents

- 2.1.1 NASA Document # DOC-128694, LSP Composite Substrate Manufacturing Processing Guide**
- 2.1.2 NASA Document # DOC-128695, LSP Composite Substrate NDE Assessment Manual**
- 2.1.3 NASA Document # DOC-128696, LSP Composite Substrate Lightning Test Operations Manual**
- 2.1.4 SAE ARP5412A, Aircraft Lightning Environment and Related Test Waveforms Rev A**
- 2.1.5 ASTM E2580 – 07, Standard Practice for Ultrasonic Testing of Flat Panel Composites and Sandwich**

2.2 Nomenclature

AEST - Atmospheric Environment Safety Technologies
ARP – Aerospace Recommended Practice
CFRP – Carbon Fiber Reinforced Plastic
FAA – Federal Aviation Administration
IWWF – Interwoven Wire Fabric
LSP – Lightning Strike Protection
NDI – Nondestructive Inspection
SAE – Society of Automotive Engineers

3 POST-TEST INSPECTIONS/EVALUATIONS

To ensure consistency in lightning strike protection evaluations, perform the inspections and evaluations detailed in this section.

The tested panels will be nondestructively and destructively examined for damage including fiber breakout or backside fracture of the panel.

Nondestructive evaluations include visual surface damage area assessments, macro-photography, damage depth assessments by pulse-echo ultrasonic methods and optional metal damage assessment by X-ray inspection.

Destructive inspection is performed by taper sanding and documented by macro-photography after completion of the nondestructive inspections. The results of this evaluation must be clearly noted in the deliverable report.

The following list is a summary of the steps to be performed:

1. Visually examine both sides of panel for evidence of damage. Determine if back side of panel has been damaged. Mark outline of visible damage on panel side(s), including paint blistering, with indelible non-black marker, color #1. Ref section 3.1.1.
2. Do ultrasonic pulse-echo examination of panel from both sides and mark outline of damage on front side of panel with indelible non-black marker, color #2 (perceptibly different from color #1). Ref section 3.1.2.
3. Perform optional X-ray examination of panel. Overlay X-ray film (or 1:1 rendering of digital image) on panel and mark outline of damage on front side of panel with indelible non-black marker, color #3 (perceptibly different from colors #1 and #2). Ref section 3.1.3.
4. Mark a key on each panel delineating mapping between color selection and inspection method. Then photograph both sides of panel to capture all damaged areas and markings.
5. Measure and calculate damaged area. Ref section 3.1.1.
6. Taper sand from the front side to remove damaged material under strike point and any simulated lightning reattachment points until only undamaged material remains. Ref section 3.2.
7. Measure remaining thickness (if any) of undamaged panel material in locus of attachment point(s) using deep-throat micrometer.
8. Photograph the areas where damaged material was removed in step 6.

All indelible markers used to record damage boundaries shall be resistant to water and isopropyl alcohol. No solvents or cleaning agents shall be applied to panels except for water and isopropyl alcohol.

Note that all photographs will be shot at 6 megapixel or higher resolution using a color digital camera and good photographic technique. Include a scale aligned in both X and Y axes and panel identification number in all photos. All images shall be provided in .TIFF or .JPEG formats.

Frequently, damaged regions are circular in shape and an average diameter can be measured and used in an area calculation. There are also instances where the damage is more rectangular or parallelogram shaped and length and width measurements can be made and used to calculate the area of a damage region. If the damage is of irregular shape, use geometric calculations or computer calculations based on image analysis of a digitized photo to determine area of damage.

Detailed instructions for each step with optional processes for more detailed information are in the sections that follow.

3.1 Non-Destructive Damage Area Assessments

Surface damage area assessments are made by general visual examination, ultrasound and optional X-ray techniques. The visual damage areas are obtained by naked eye visual examination of the panels and marking of all damage including paint blistering. Pulse-echo ultrasonic technique provides the ability to identify borders between damaged areas (i.e., areas containing delaminations between composite plies) and undamaged areas in the composite through use of instrumented NDI equipment. The optional X-ray technique provides X-ray films or photos which can be used to determine areas of missing LSP metal elements that cannot be discerned using visual or pulse-echo ultrasonic methods.

3.1.1 Visual Damage Assessment

Accurate measurements of the damage should be made on the front-side of each panel (i.e, the side that is paint-finished and is exposed directly to the simulated lightning strike) and back-side (unfinished side) of each panel if there is any back-side damage (use a magnifying glass if necessary to examine for back-side damage as this can be difficult to detect). Visual

damage assessment is performed by measurement and calculation of the area of the damage. The visual damage area includes the areas of minor damage such as paint pitting or blistering as well as major damage such as missing material and CFRP fiber breakout and back side fracture. Smoke trails may be present after lightning testing, they can extend beyond where the paint damage is noticeable and may be an artifact of the test method used. The presence or quantity of smoke trail indications is not to be considered with respect to the quantification of damaged areas. Once the extent of visual damage is determined, draw a line around the damage using a non-black indelible marker, color #1. Please note in the deliverable report if the back of the test article has been damaged or not.

3.1.2 Pulse-Echo Ultrasonic Assessment

Perform pulse echo ultrasonic testing to determine extent or boundary of non-visible damage in the CFRP of the test article panel. Pulse echo testing should be performed to both sides of the panel. It uses a single transducer that transmits and receives longitudinal waves in the range of 0.5 to 20 MHz. An ultrasonic indication (flaw) is an area with ultrasonic attenuation that is at least 6dB larger than the attenuation of the adjacent areas without flaws or defects. Delaminations in composites are also exhibited as acoustic signal returns at depth levels less than the full thickness of a laminate. This procedure, which is explained in Reference 2.1.5, is a manual operation. Draw outline of damaged area as determined by pulse echo technique on the panel using non-black indelible marker, color #2.

3.1.3 X-ray Assessment (Optional)

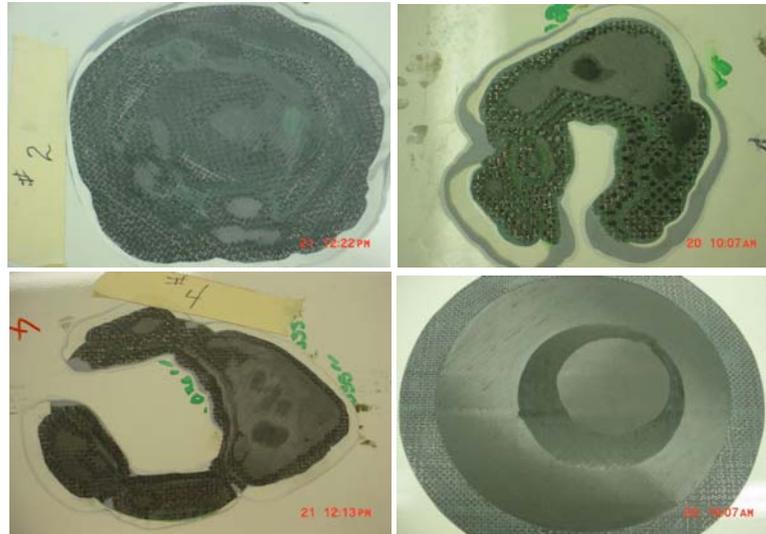
X-Ray damage assessment may be performed if damage to the protective metal layer beyond what can be detected by visual or ultrasonic means is suspected. Lightning Strike Protection materials based on Interwoven wire fabric (IWWF) concepts tend to be damaged more easily than metal foil or expanded metal foil. X-ray is performed with either film or digital techniques, and X-Ray resolution is good down to five microns. This technique senses a change in density to detect missing metal. From the X-ray results, mark the outline of damage on the panel using an indelible non-black marker, color #3.

3.2 Destructive Damage Assessments

Destructive assessment involves taper sanding of the damaged area of the part to determine how deep the damage actually is since pulse-echo ultrasound techniques have difficulty finding damage regions laying deeper

into a laminate than damaged regions laying closer to the surface contacting the ultrasonic transducer. Perform the process as follows:

- 1) Clean panel to remove loose paint taking care not to remove markings that identify visual and NDI damage.
- 2) Carefully inspect the panel to determine if there is a complete puncture through the panel. If water or isopropyl alcohol can pass through the panel, it shall be considered as punctured. Record remaining undamaged depth of laminate as "0.0 cm".
- 3) From the front side only, remove damaged material under strike point in a generally circular area by:
 - a) Taper sanding (scarf) a relatively circular region under the strike point to a depth sufficient to remove all the damaged plies. Use pulse-echo ultrasonics to verify that the remaining material after sanding is undamaged. Repeat sanding until there are no more indications. Note that this could result in eventually sanding completely through the panel.
 - b) Taper sanding is performed either manually or mechanically using various grits of sandpaper and sandpaper grit cutting wheels, beginning with coarse (~100 grit) sandpaper. Finish sand with a 240 grit or finer sanding disk.
 - c) Taper sand at a ~30:1 pitch (approximately 0.6 cm per ply for the tape and fabric materials employed in the panel (see Reference 2.1.1), the ratio of the taper length to depth. The panels contain 16 plies of CFRP prepreg tape (with a cured thickness of ~7.5 mils/ply) sandwiched between an outer ply on each side of prepreg cloth (with a cured thickness of ~8 mils/ply).
- 4) Find and measure a minimum value for remaining thickness of each panel using deep-throat micrometer and count the plies removed (from the sanding operation) in the region of minimum thickness. The taper sand pitch and ply orientation allow the number of plies damaged to be easily counted.
- 5) Solvent clean and wipe dry.
- 6) Photograph the areas where damaged material was removed. Verify that undamaged plies can be seen and counted, otherwise adjust lighting and repeat photograph. Take additional close-up (macro) photos if necessary to show detail.
- 7) Examples of panels destructively examined in this fashion are given below:



4 DELIVERABLES

The following items will be included in the deliverable report:

- 1) All front and back side photos taken to record artifacts from testing (e.g., delamination, fiber breakout, smoke trails, paint blistering, etc.) and boundaries of damage visible to eye, pulse-echo ultrasonics and X-ray examination(if applicable).
- 2) Final calculated values of damage areas (in units of cm^2) for each panel for all inspections performed (visual, ultrasonic, X-ray).
- 3) Photo(s) of panels with damaged material removed.
- 4) Minimum thickness values and removed ply counts for all panels.

REPORT DOCUMENTATION PAGE

*Form Approved
OMB No. 0704-0188*

The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.
PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.

1. REPORT DATE (DD-MM-YYYY) 01-11 - 2013		2. REPORT TYPE Contractor Report		3. DATES COVERED (From - To)	
4. TITLE AND SUBTITLE LSP Composite Substrate Destructive Evaluation Test Assessment Manual			5a. CONTRACT NUMBER NNL10AA05B		
			5b. GRANT NUMBER		
			5c. PROGRAM ELEMENT NUMBER		
6. AUTHOR(S) Kovach, Daniel J.; Erickson, Grant J.			5d. PROJECT NUMBER		
			5e. TASK NUMBER		
			5f. WORK UNIT NUMBER 62897.02.04.07.20		
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) NASA Langley Research Center Hampton, Virginia 23681			8. PERFORMING ORGANIZATION REPORT NUMBER Document Number: DOC-128697		
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) National Aeronautics and Space Administration Washington, DC 20546-0001			10. SPONSOR/MONITOR'S ACRONYM(S) NASA		
			11. SPONSOR/MONITOR'S REPORT NUMBER(S) NASA/CR-2013-218043		
12. DISTRIBUTION/AVAILABILITY STATEMENT Unclassified - Unlimited Subject Category 24 Availability: NASA CASI (443) 757-5802					
13. SUPPLEMENTARY NOTES Langley Technical Monitor: George N. Szatkowski					
14. ABSTRACT 200Word Limit					
15. SUBJECT TERMS Composites; Lightning					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			STI Help Desk (email: help@sti.nasa.gov)
U	U	U	UU	16	19b. TELEPHONE NUMBER (Include area code) (443) 757-5802