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LSP Composite Susbtrate Manufacturing Processing Guide

Daniel J. Kovach and Kenneth H. Griess
The Boeing Company, Seattle, Washington

August 2013

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FOREWORD

The information described in this report was authored by Dan Kovach and Ken Griess.

The author would like to acknowledge the contributions and support of Noel Gerken and Grant Erickson.

Revision 1 of this document contains provisions for the use of a surface film in combination with the Expanded Copper Foil (ECF) specified for use as a baseline Lightning Strike Protection (LSP) scheme.

1 SCOPE

This recommended practice establishes a generic reference standard that will accommodate lightning strike testing of composite (carbon/epoxy) panels.

1.1 Purpose

This document is intended to define Carbon Fiber Reinforced Plastic (CFRP) test panel configurations that can be employed for the purposes of evaluating the protection capabilities of Lightning Strike Protection (LSP) materials developed by the Aerospace Industry. The configurations are intended to provide consistent behavior in their response to simulated lightning strikes at pre-defined levels when tested by a capable vendor according to a test procedure written to enable consistent results (ref section 2.1.2). In response to an attachment of a simulated lightning strike on a CFRP panel, one can expect to see various levels of ablation and delamination, both through the thickness of the panel and with respect to the amount of panel surface area that exhibits damage.

Panel configurations defined in this document include:

- An "unprotected" configuration 128694-1 (ref section 4.1), consisting of a cured CFRP laminate stackup of tape and fabric prepregs, coated with a typical aerospace primer and paint finishing scheme, attached to aluminum grounding bars intended to draw electrical current from the lightning attachment point to the panel edges and thus to ground.
- A "protected" configuration 128694-2 (ref section 4.1), wherein a layer of an LSP material form often used in the Aerospace Industry is included in the laminate stackup prior to cure. The CFRP materials, finishes and grounding arrangement for this configuration are the same as for the "unprotected" configuration.

1.2 Background

The growing application of composite materials in commercial aircraft manufacturing has significantly increased the risk of aircraft damage from lightning strikes. With this growth in composite usage, new technical challenges arise. Composite skinned aircraft are far 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 conductive aluminum skinned aircraft. The electrical current incident on an aircraft from a typical lightning strike can exceed 200,000 amperes, occurring in less than 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 known 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. Lightning test standard waveforms are simplified laboratory-generated waveforms that represent key parameters including peak current, total energy transferred & signal rise time to simulate the statistical lightning environment established under previous Society of Automotive Engineers (SAE) standard developments. To ensure flight safety, LSP studies are conducted to gain FAA certification to show performance characteristics of the conductive layers placed over composite substrates and subjected to lightning direct effect electrical waveforms for flight safety air-worthiness standards testing. Test results are often incomparable due to variability in test procedures & practices between independent LSP studies. This prevents the ability to acquire performance correlations between different LSP data sets.

A universal common practice procedure is needed to add conformity in future lightning strike protection evaluations to allow performance correlations across data sets. This document specifies the embodiment of a physical finished and grounded CFRP panel that defines the baseline test specimen from which further damage evaluations can proceed. In addition, this document specifies a configuration of the test specimen which has been modified to include a common LSP material incorporated into the laminate. It is expected that commercial vendors of existing and emerging LSP materials and concepts would use the behavior of this protected configuration as a baseline performance standard which they would try to meet or exceed. It is recognized that many factors besides damage protection are involved in the selection of an appropriate LSP for a particular system (e.g., cost, weight, corrosion resistance, shielding effectiveness); this document strives primarily to address inconsistencies in the 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 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 this standard. Note that the pre-test Nondestructive Examination requirements for these panels is contained here-in, but is also provided as a standalone document (see section 2.1.1) in accordance with the deliverable provisions of the task order defining these documents. Following manufacture and inspection, these panels will be subject to simulated strikes per the procedure identified in section 2.1.2. Following test, it is intended for the panels to be qualitatively and quantitatively evaluated for their response, using the guidelines contained in the procedure identified in section 2.1.3.

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 (757-864-6149).

2 REFERENCES

2.1 Applicable Documents

2.1.1 NASA Document # DOC-128695 – LSP Composite Substrate NDE Assessment Manual

2.1.2 NASA Document # DOC-128696 – LSP Composite Substrate Lightning Test Operations Manual

2.1.3 NASA Document # DOC-128697 - LSP Composite Substrate Destructive Evaluation Test Assessment Manual

2.2 Nomenclature

AEST - Atmospheric Environment Safety Technologies
AN – Air Force Navy Standard
CFRP – Carbon Fiber Reinforced Plastic
CRES – Corrosion resistant steel
DN – Drawing Note
ECF – Expanded Copper Foil
FAA – Federal Aviation Administration
LSP – Lightning Strike Protection
MS – Military Standard
MIL – Military Specification
NCAMP - National Center for Advanced Materials Performance
NIAR – National Institute for Aviation Research
NMS – NCAMP Material Specification
NPS - NCAMP Process Specification
SAE – Society of Automotive Engineers
SURF – Surfacer

2.3 Table of Resource or Information Links

Hexcel - HexPly	http://www.hexcel.com/Resources/DataSheets/Prepreg-Data-Sheets/8552_us.pdf
Dexmet - ECF	http://www.dexmet.com
Cytec - Surfacer	https://www.cytec.com/engineered-materials/products/Datasheets/SurfaceMaster905C.pdf
NCAMP - Standards	http://www.niar.twsu.edu/coe/ncamp.asp https://www.niar.wichita.edu/NCAMPPortal/default.aspx https://www.niar.wichita.edu/NCAMPPortal/Contact/tabid/104/Default.aspx See bottommost link for contact to get NCAMP account to procure documents.

Table 2.3-1 Web Links to Material Vendors and Standards

3 TECHNICAL REQUIREMENTS

3.1 Composite Panel Fabrication and Material

3.1.1 General Requirements

All aspects of composite fabrication including processes and equipment (material handling, surface preparation, clean room, autoclave, machining, drilling, etc.) should be in accordance to industry standards.

3.1.2 Materials

The following industry specifications and material designations listed are for information purposes. Specific materials will be designated for each design and will be noted within the engineering drawing and/or notes.

Tape: Hexcel 8552/AS4 (HexPly 8552/AS4), Hexcel Inc., Stamford, CT.

Fabric: Hexcel 8552/AS4 (HexPly 8552 / A193-PW, 3K-70-PW), Hexcel Inc., Stamford, CT.

Lightning Protection:
Dexmet 3CU7-100FA, expanded copper foil (ECF), Dexmet Corp., 22 Barnes Industrial Road South, Wallingford, CT.
Cytec Surfacemaster 905C Composite Surfacing Film (SURF), 0.035psf, Cytec Engineered Materials, Tempe, Arizona, U.S.A. (Global Headquarters)

3.1.3 Laminate

Laminates are to be designed per common aerospace industry practices (balanced, symmetric and sequence). The typical lightning strike panel will be quasi-isotropic in nature with a fabric ply on each side of the laminate.

Typical Laminates:

Unprotected:
16 ply tape with 2 ply fabric (as follows):
[(0/90F)/45/90/-45/0/45/90/-45/0/0/-45/90/45/0/-45/90/45/(0/90F)]

Protected:
16 ply tape with 2 ply fabric and one ply lightning protection (as follows):
[(SURF)(ECF)(0/90F)/45/90/-45/0/45/90/-45/0/0/-45/90/45/0/-45/90/45/(0/90F)]

Any "protective configuration" that is cured into the laminate should be added to the tool side of the laminate.
Specific laminates will be designated for each design and will be noted within the engineering drawing and/or notes.

3.1.4 Cure Cycle

An example of an industry standard is seen below.
Lay-up, bag and cure laminate per NCAMP Process Specification NPS 81228 'Fabrication of NMS 128 Qualification, Equivalency and Acceptance Test Panels (Hexcel 8552 and 8552S).'

3.1.5 Finish

Only the tool side surface (lightning attach side) need be primed and painted with a top coat.
Paint prep: Solvent clean and scuff sand to remove surface contamination.

Primer: Use an epoxy primer applied per proper aerospace specifications.

Top Coat: Apply aerospace grade top coat per proper aerospace specifications.

Specific finish will be designated for each design and will be noted within the engineering drawing and/or notes.

3.2 Acceptance Criteria

Use industry standard Through Transmission Ultrasonic (TTU) ‘C’ Scan inspection methods to validate cured laminate quality. Any deviations must be clearly noted as such in the final test data and report.

3.3 Metal Frame Fabrication and Material

3.3.1 General Requirements

All aspects of metal fabrication should be in accordance to industry standards.

3.3.2 Materials

It is recommended that common aluminum sheet stock is used for the frame. The recommended alloys are 2024, 6061 and 7075. There is no requirement as to temper of the alloy. Specific design details will be designated and noted within the engineering drawing(s) and/or notes.

3.4 Lightning Strike Panel Assembly

3.4.1 General Requirements

This section contains the requirements for the attachment of the finished CFRP panel (both protected and unprotected configurations) to metallic grounding bars intended to pull current from the edges of the panel to ground (thus completing the electrical circuit from the source of the simulated attachment through the panel). This configuration is suitable for evaluating co-cured LSP material configurations.

For alternative LSP material configurations such as conductive finishes or adhesively-bonded appliqués, other grounding configurations may be more appropriate. In such cases, it is important to recognize that alternative grounding configurations must be representative of the proposed installation conditions intended for the end-product, as the expected performance of test panels employing such alternative materials may be highly sensitive to the grounding configuration used. Care must be taken in the selection of an alternative grounding configuration to avoid generating unrealistically-optimistic test results.

Assistance in the selection of alternative grounding configurations may be acquired by contacting the AEST Task Monitor (ref section 1.3).

3.4.2 Conductive Frame Attach

The function of the fasteners is to provide a conductive path from the panel to the frame and eventually into the test equipment. Common steel or CRES fasteners are suitable. The following fastener example is common and easily acquired through local fastener vendors:

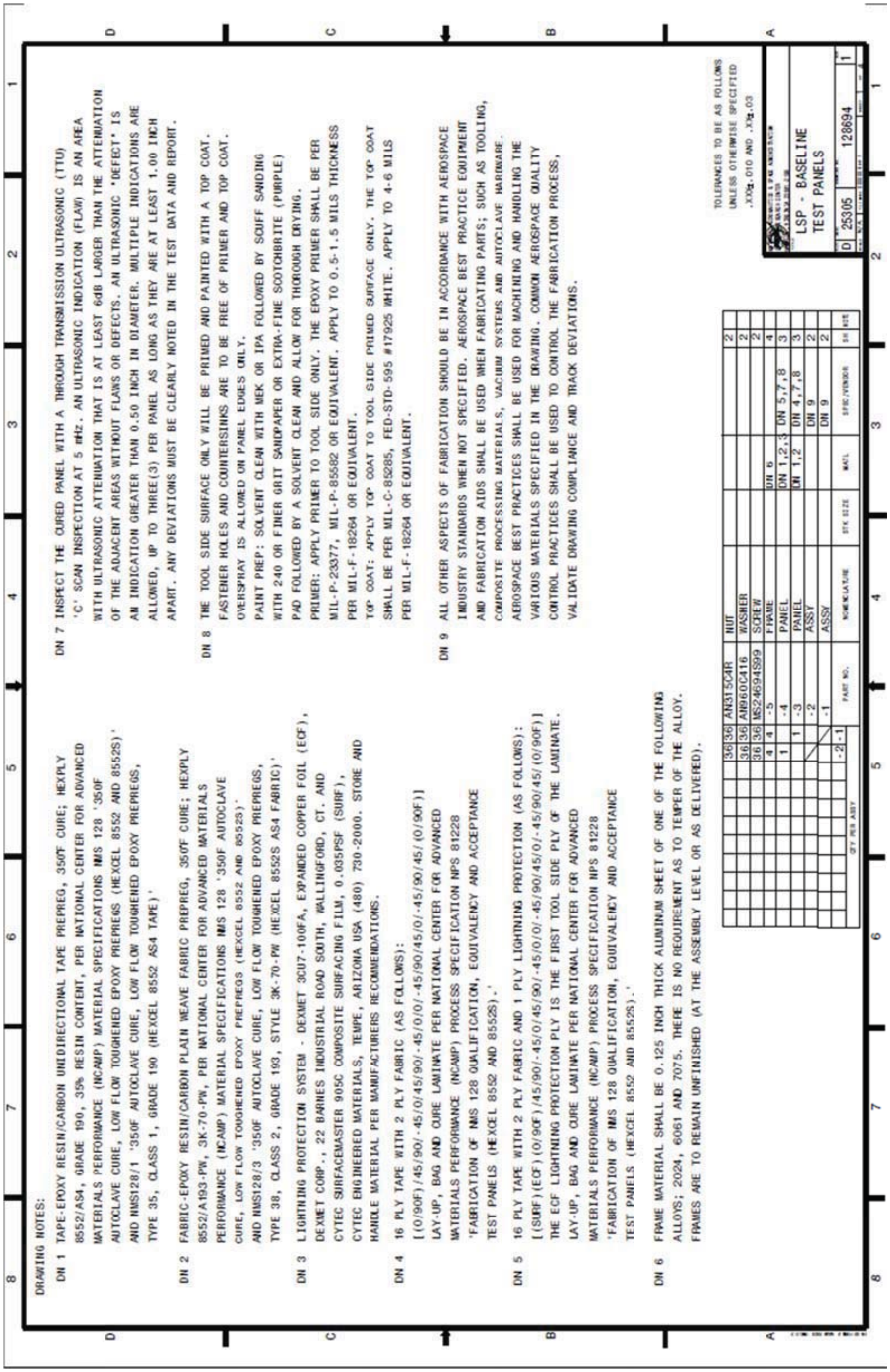
- MS24694S99 (¼-28 cad plated alloy steel bolt, 100 degree head, Phillips drive bolt that has a 0.25" grip).
- AN315C4R (¼-28 CRES nut).
- AN960C416 (¼" CRES washer).

Specific design details will be designated and noted within the engineering drawing(s) and/or notes.

4 ENGINEERING DESIGN DRAWINGS

The drawings included in this document are considered to be baseline drawings for both the "unprotected" configuration (with no lightning protection scheme) and the baseline "protected" configuration. For any new lightning protection schemes, the "unprotected" drawing can be used for the basic panel design. In adding the protection scheme, a determination must be made as to whether the scheme is cured into the laminate, added to (or in place of) the finish, or added on top of the standard finish.

4.1 Design Drawings



DRAWING NOTES:

DN 1 TAPE-EPOXY RESIN/CARBON UNIDIRECTIONAL TAPE PREPREG, 350°F CURE; HEXPLY 8552/AS4, GRADE 190, 35% RESIN CONTENT, PER NATIONAL CENTER FOR ADVANCED MATERIALS PERFORMANCE (NCAMP) MATERIAL SPECIFICATIONS NMS 128 '350F AUTOCLAVE CURE, LOW FLOW TOUGHENED EPOXY PREPREGS (HEXCEL 8552 AND 8552S)' AND NMS128/1 '350F AUTOCLAVE CURE, LOW FLOW TOUGHENED EPOXY PREPREGS, TYPE 35, CLASS 1, GRADE 190 (HEXCEL 8552 AS4 TAPE)'

DN 2 FABRIC-EPOXY RESIN/CARBON PLAIN WEAVE FABRIC PREPREG, 350°F CURE; HEXPLY 8552/A193-PW, 3K-70-PW, PER NATIONAL CENTER FOR ADVANCED MATERIALS PERFORMANCE (NCAMP) MATERIAL SPECIFICATIONS NMS 128 '350F AUTOCLAVE CURE, LOW FLOW TOUGHENED EPOXY PREPREGS (HEXCEL 8552 AND 8552S)' AND NMS128/3 '350F AUTOCLAVE CURE, LOW FLOW TOUGHENED EPOXY PREPREGS, TYPE 38, CLASS 2, GRADE 193, STYLE 3K-70-PW (HEXCEL 8552S AS4 FABRIC)'

DN 3 LIGHTNING PROTECTION SYSTEM - DEXMET 3CU7-100FA, EXPANDED COPPER FOIL (ECF), DEXMET CORP., 22 BARNES INDUSTRIAL ROAD SOUTH, WALLINGFORD, CT. AND CYTEC SURFACEMASTER 905C COMPOSITE SURFACING FILM, 0.035PSF (SURF), CYTEC ENGINEERED MATERIALS, TEMPE, ARIZONA USA (480) 730-2000. STORE AND HANDLE MATERIAL PER MANUFACTURERS RECOMMENDATIONS.

DN 4 16 PLY TAPE WITH 2 PLY FABRIC (AS FOLLOWS): [(0/90F)/45/90/-45/0/45/90/-45/0/0/-45/90/45/0/-45/90/45/(0/90F)] LAY-UP, BAG AND CURE LAMINATE PER NATIONAL CENTER FOR ADVANCED MATERIALS PERFORMANCE (NCAMP) PROCESS SPECIFICATION NPS 81228 'FABRICATION OF NMS 128 QUALIFICATION, EQUIVALENCY AND ACCEPTANCE TEST PANELS (HEXCEL 8552 AND 8552S).'

DN 5 16 PLY TAPE WITH 2 PLY FABRIC AND 1 PLY LIGHTNING PROTECTION (AS FOLLOWS): [(SURF)(ECF)(0/90F)/45/90/-45/0/45/90/-45/0/0/-45/90/45/0/-45/90/45/(0/90F)] THE ECF LIGHTNING PROTECTION PLY IS THE FIRST TOOL SIDE PLY OF THE LAMINATE. LAY-UP, BAG AND CURE LAMINATE PER NATIONAL CENTER FOR ADVANCED MATERIALS PERFORMANCE (NCAMP) PROCESS SPECIFICATION NPS 81228 'FABRICATION OF NMS 128 QUALIFICATION, EQUIVALENCY AND ACCEPTANCE TEST PANELS (HEXCEL 8552 AND 8552S).'

DN 6 FRAME MATERIAL SHALL BE 0.125 INCH THICK ALUMINUM SHEET OF ONE OF THE FOLLOWING ALLOYS; 2024, 6061 AND 7075. THERE IS NO REQUIREMENT AS TO TEMPER OF THE ALLOY. FRAMES ARE TO REMAIN UNFINISHED (AT THE ASSEMBLY LEVEL OR AS DELIVERED).

DN 7 INSPECT THE CURED PANEL WITH A THROUGH TRANSMISSION ULTRASONIC (TTU) 'C' SCAN INSPECTION AT 5 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. AN ULTRASONIC 'DEFECT' IS AN INDICATION GREATER THAN 0.50 INCH IN DIAMETER. MULTIPLE INDICATIONS ARE ALLOWED, UP TO THREE(3) PER PANEL AS LONG AS THEY ARE AT LEAST 1.00 INCH APART. ANY DEVIATIONS MUST BE CLEARLY NOTED IN THE TEST DATA AND REPORT.

DN 8 THE TOOL SIDE SURFACE ONLY WILL BE PRIMED AND PAINTED WITH A TOP COAT. FASTENER HOLES AND COUNTERSINKS ARE TO BE FREE OF PRIMER AND TOP COAT. OVERSPRAY IS ALLOWED ON PANEL EDGES ONLY.
PAINT PREP: SOLVENT CLEAN WITH MEK OR IPA FOLLOWED BY SCUFF SANDING WITH 240 OR FINER GRIT SANDPAPER OR EXTRA-FINE SCOTCHBRITE (PURPLE) PAD FOLLOWED BY A SOLVENT CLEAN AND ALLOW FOR THOROUGH DRYING.
PRIMER: APPLY PRIMER TO TOOL SIDE ONLY. THE EPOXY PRIMER SHALL BE PER MIL-P-23377, MIL-P-85582 OR EQUIVALENT. APPLY TO 0.5-1.5 MILS THICKNESS PER MIL-F-18264 OR EQUIVALENT.
TOP COAT: APPLY TOP COAT TO TOOL SIDE PRIMED SURFACE ONLY. THE TOP COAT SHALL BE PER MIL-C-85285, FED-STD-595 #17925 WHITE. APPLY TO 4-6 MILS PER MIL-F-18264 OR EQUIVALENT.

DN 9 ALL OTHER ASPECTS OF FABRICATION SHOULD BE IN ACCORDANCE WITH AEROSPACE INDUSTRY STANDARDS WHEN NOT SPECIFIED. AEROSPACE BEST PRACTICE EQUIPMENT AND FABRICATION AIDS SHALL BE USED WHEN FABRICATING PARTS; SUCH AS TOOLING, COMPOSITE PROCESSING MATERIALS, VACUUM SYSTEMS AND AUTOCLAVE HARDWARE. AEROSPACE BEST PRACTICES SHALL BE USED FOR MACHINING AND HANDLING THE VARIOUS MATERIALS SPECIFIED IN THE DRAWING. COMMON AEROSPACE QUALITY CONTROL PRACTICES SHALL BE USED TO CONTROL THE FABRICATION PROCESS, VALIDATE DRAWING COMPLIANCE AND TRACK DEVIATIONS.

QTY PER ASSY -2	QTY PER ASSY -1	PART NO.	NOMENCLATURE	STK SIZE	MATL	SPEC/VENDOR	SH	SIZE
36	36	AN315C4R	NUT				2	
36	36	AN960C416	WASHER				2	
36	36	MS24694S99	SCREW				2	
4	4	-5	FRAME		DN 6		4	
1		-4	PANEL		DN 1,2,3	DN 5,7,8	3	
	1	-3	PANEL		DN 1,2	DN 4,7,8	3	
		-2	ASSY			DN 9	2	
		-1	ASSY			DN 9	2	

TOLERANCES TO BE AS FOLLOWS UNLESS OTHERWISE SPECIFIED .XX±.010 AND .X±.03

LSP - BASELINE TEST PANELS

D 25305 128694 1

Figure 4.1-1 LSP Parts List and Notes Sheet 1

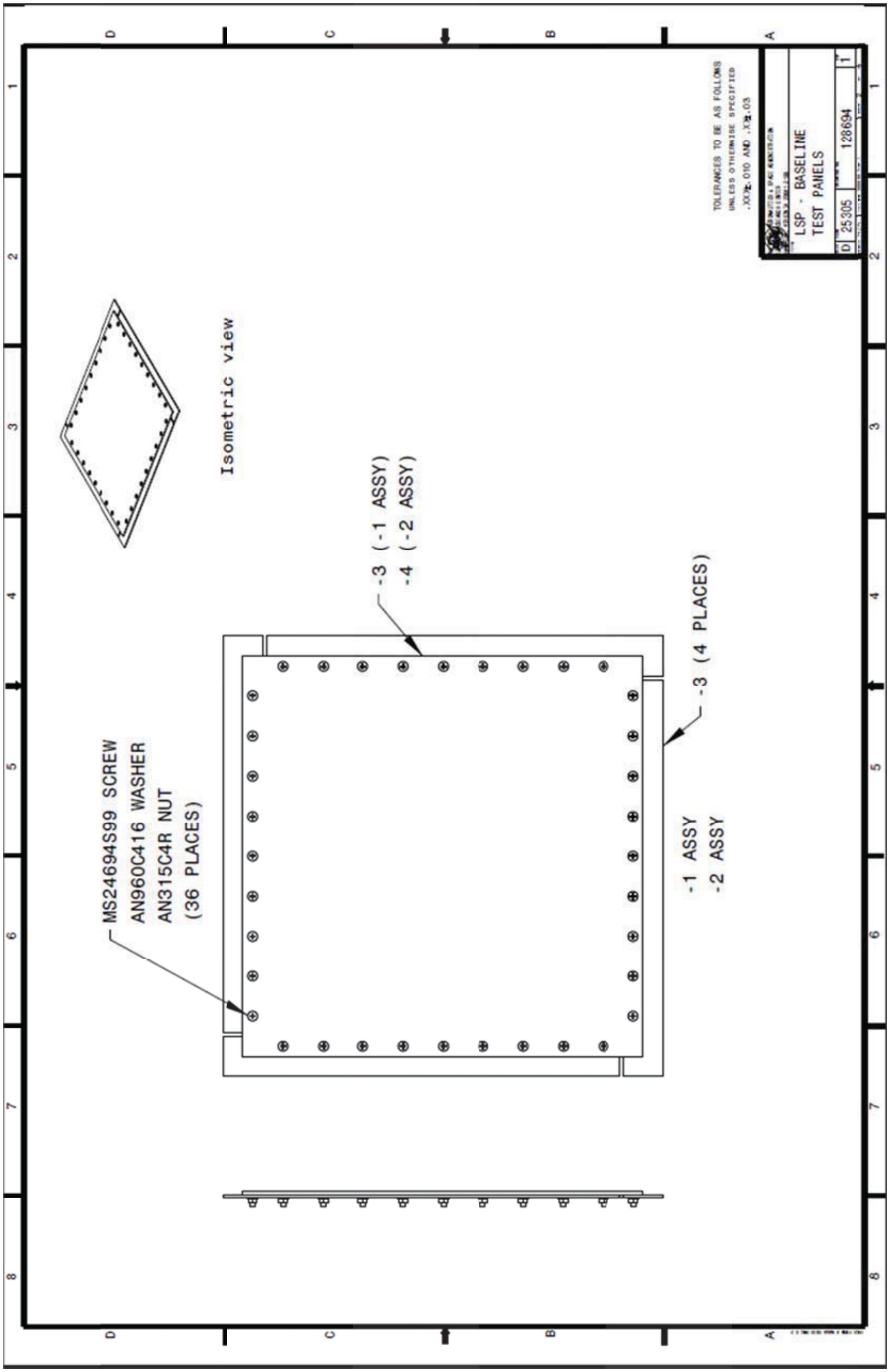


Figure 4.1-2 LSP Panel Assembly Sheet 2

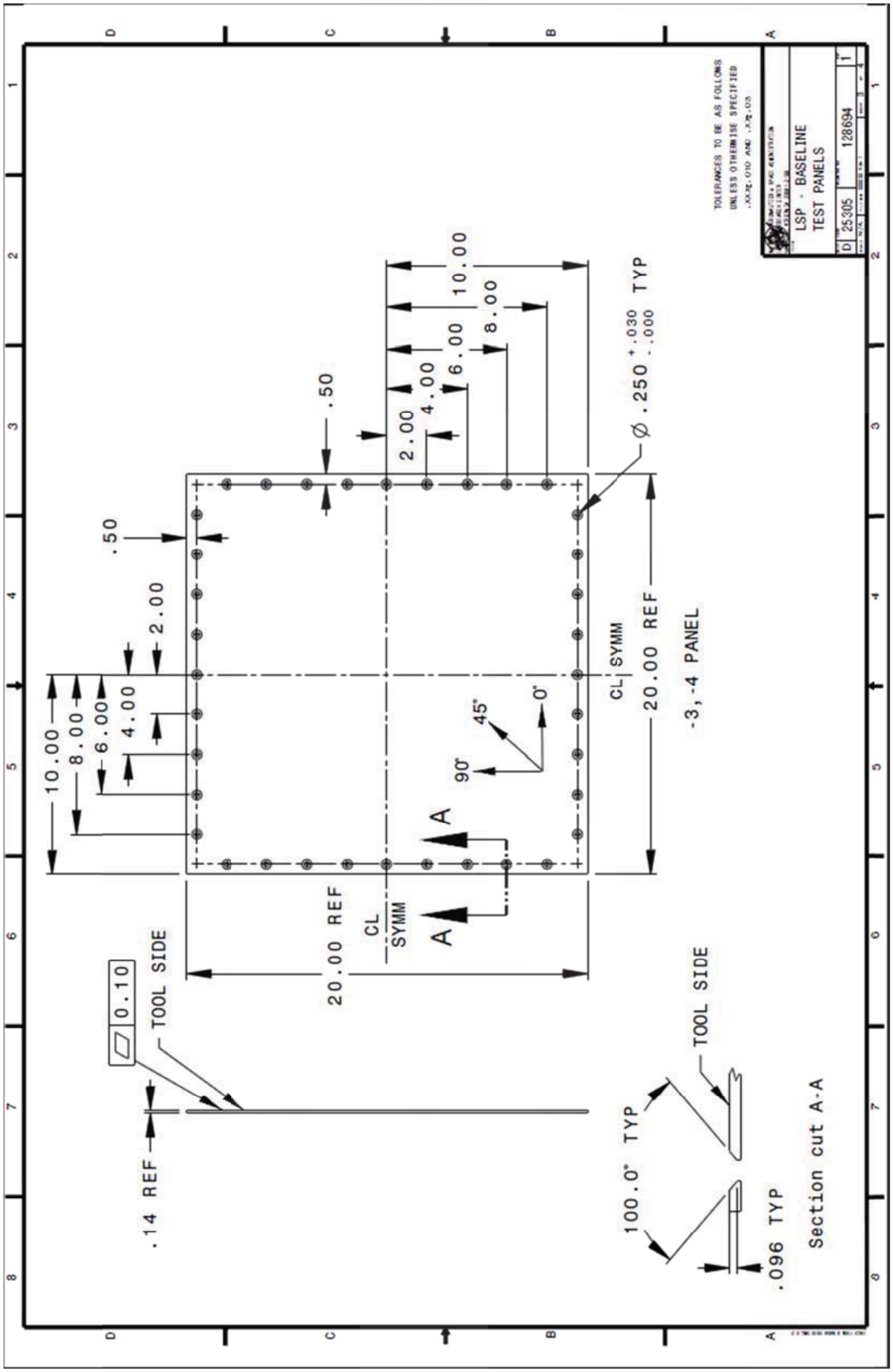


Figure 4.1-3 LSP Panel Detail Sheet 3

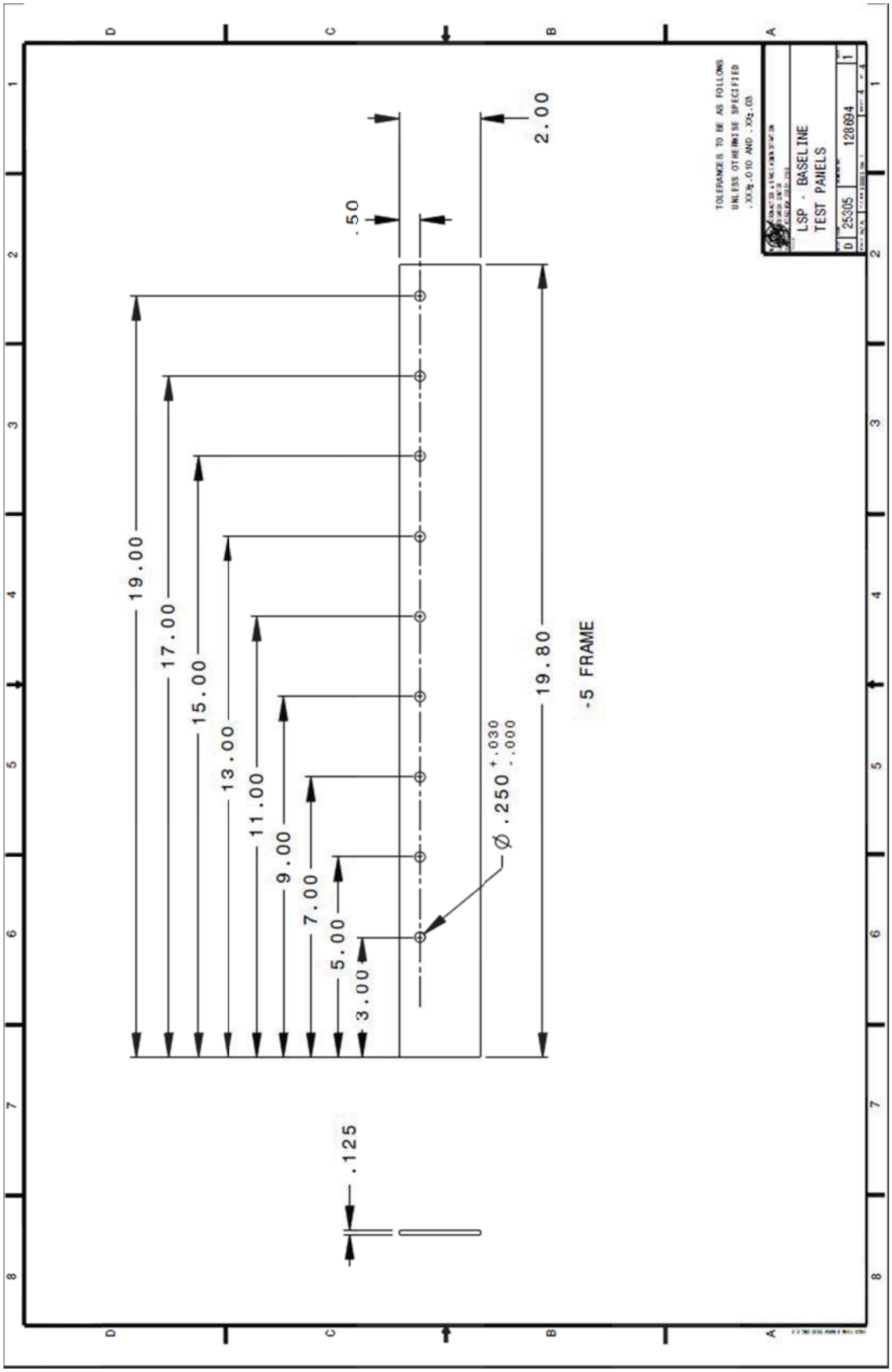


Figure 4.1-4 LSP Frame Detail Sheet 4

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14. ABSTRACT
Manufacturing procedures to fabricate protected and unprotected Carbon Fiber Reinforced Plastic (CFRP) test panel configurations that can be employed for the purposes of evaluating the protection capabilities of Lightning Strike Protection (LSP) materials are documented in NASA DOC-128694. The composite test panels are intended to provide consistent behavior in their response to simulated lightning strikes at pre-defined levels when tested by a capable vendor according to a test procedure written to enable consistent results. It is expected that commercial vendors of existing and emerging LSP materials and concepts would use the behavior of this protected configuration as a baseline performance standard which they would try to meet or exceed. The unprotected configuration consists of a cured CFRP laminate of tape (Hexcel HexPly 8552/AS4) and fabric (Hexcel HexPly 8552 / A193-PW, 3K-70-PW) prepregs, coated with a typical aerospace primer (0.5-1.5 mils thick) and paint (4-6 mils thick) finishing scheme. The protected configuration contains a top LSP layer made up of Cytec Surfacemaster 905C Composite Surfacing Film above Dexmet 3CU7-100FA expanded copper foil and is included in the laminate stackup prior to cure.

15. SUBJECT TERMS
Composites; Damage protection; Lightning

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