Repair Design, Test, and Process Considerations for Lightning Strikes

CACRC/MIL-HDBK-17 Conference
Amsterdam, Netherlands May 7-11, 2007

John M. Welch

Associate Technical Fellow – Composite Structures

Propulsion Systems and Structures

May 7, 2007

john.m.welch@spiritaero.com

Data for Repair Design – What was needed….

Spirit Nacelle Product Owners realized need to have additional lightning strike damage test data for existing and future products.

Experiences from prior products showed that damage events occurred due to lightning strikes on structure in service.

The product being analyzed is thin-faced, honeycomb reinforced, sandwich structure.

Testing would provide results from a variety of existing and evolving mesh protection schemes – comparative data for Zone 1A and 1B severe strike.

Testing results would assist in creating the potential to provide a prevention kit that could be bonded onto existing structure having no protection.

The goal then, was to create an understanding of the effects of the lightning strike event, and then to find a solution to avoid damage for future and existing products.

Lightning Strike Testing and Creation of Damage Prevention Kit

Test Panel Configurations

Current Test Values for Lightning Strike Testing

Baseline Nacelle Configuration

Comparative Test Panel Results – Pertinent Coupons

Non-Destructive Evaluation of Post-Struck Test Panels – Damage Assessment

Construction of Lightning Strike Damage Prevention Kit – Proof of Concept.

Configurations Represented by Test Panels, 29 total panels- Test Strategy

1)Aramid Core

- 1 inch and 0.50 inch thick coupons to see if thickness made any difference
- Representative of inlet, fan cowl, and T/R outer cowl structure – all programs
- Tested with and without lightning strike protection
- Tested Interwoven Phos-Bronze, Copper, and Aluminum mesh lightning strike materials
- Tested both Zone 1A and 1B strikes – i.e. the most severe the structure could see
- Tested different types of isolation ply for cost saving potential
- Tested existing protection lay-up as “baseline”
- Tested different splice combinations

2)Fiberglass Acoustic Core

- 1 inch and 0.50 inch thick coupons to see if thickness made any difference
- Representative of inlet and fan duct T/R outer acoustic structure – all programs
- Tested with and without lightning strike protection
- Tested Interwoven Phos-Bronze, Copper, and Aluminum mesh lightning strike materials
- Tested both Zone 1A and 1B strikes – i.e. the most severe the structure could see
- Tested different types of isolation ply for cost saving potential
- Tested existing protection lay-up as “baseline”
- Tested different splice combinations

3)Aluminum Acoustic Core

- Tested only 1 inch thick, since in any Aluminum core application, 1 inch is min thickness
- Representative of inner wall and fan duct T/R outer acoustic structure – all programs
- Tested with and without lightning strike protection
- Tested only Aluminum mesh lightning strike materials
- Tested only Zone 1A strike

Configurations Represented by Test Panels

Panel ID	Core Type	LSP	Isolation Type	Test Type
LSP-001	1” thk Korex	D800-AL	S-2 Glass(8-154)	Zone 1A
LSP-002	1” thk Korex	D800-AL	E Glass (8-139, 108)	Zone 1A
LSP-003	1” thk Korex	D800-AL	Polyester (905SW)	Zone 1A
LSP-004	1” thk Korex	D800-AL	S-2 Glass (8-154)	Zone 1B
LSP-005	1” thk Korex	D800-AL	E Glass (8-139, 108)	Zone 1B
LSP-006	1” thk Korex	8-336-AL	S-2 Glass (8-154)	Zone 1A
LSP-007	1” thk Korex	8-336-AL	S-2 Glass (8-154)	Zone 1B
LSP-008	1” thk Korex	Cu – 905	None	Zone 1A
LSP-009*	1” thk Korex	Phos-Bronze	None	Zone 1A
LSP-010**	1” thk Korex	D800-AL	S-2 Glass (8-154)	Zone 1A
LSP-011	1” thk HRP	D800-AL	S-2 Glass(8-154)	Zone 1A
LSP-012	1” thk HRP	D800-AL	E Glass (8-139, 108)	Zone 1A
LSP-013	1” thk 4-25 AL	None	None	Zone 1A
LSP-014	1” thk HRP	D800-AL	S-2 Glass (8-154)	Zone 1B
LSP-015	1” thk HRP	D800-AL	E Glass (8-139, 108)	Zone 1B
LSP-016	1” thk HRP	8-336-AL	S-2 Glass (8-154)	Zone 1A
LSP-017	1” thk HRP	8-336-AL	S-2 Glass (8-154)	Zone 1B
LSP-018	1” thk HRP	Cu – 905	None	Zone 1A
LSP-019**	1” thk HRP	D800-AL	S-2 Glass (8-154)	Zone 1A
LSP-020	1” thk 4-25 AL	D800-AL	S-2 Glass (8-154)	Zone 1A
LSP-021	1” thk 4-25 AL	D800-AL	E-Glass (8-139, 108)	Zone 1A
LSP-022	0.5” Korex	D800-AL	S-2 Glass (8-154)	Zone 1A
LSP-023	0.5” Korex	D800-AL	E-Glass (8-139, 108)	Zone 1A
LSP-024	0.5” HRP	D800-AL	S-2 Glass (8-154)	Zone 1A
LSP-025	0.5” HRP	D800-AL	E-Glass (8-139, 108)	Zone 1A
LSP-026	1” thk Korex	None	None	Zone 1A
LSP-027	1” thk HRP	None	None	Zone 1A

- * Phos-Bronze was available to construct this panel
- ** Center splice width of panel per Figure 2. Butt splice per BAC5317-1, 0.06 inch max.
- Note: Duplicate panels for 007 and 016 were fabricated so that both Zone 1A and 1B testing could be accomplished on these configs.

J.M. Welch 5/7/2007

Test Specifications for Lightning Strike:

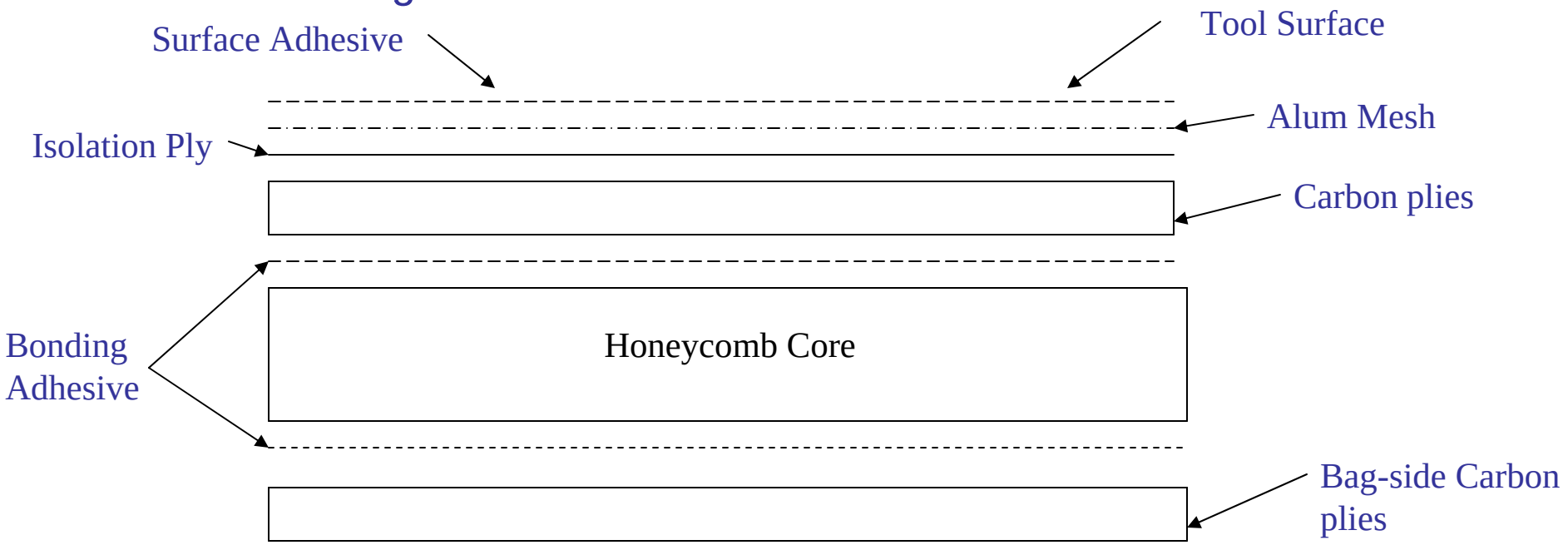
Zone 1A:

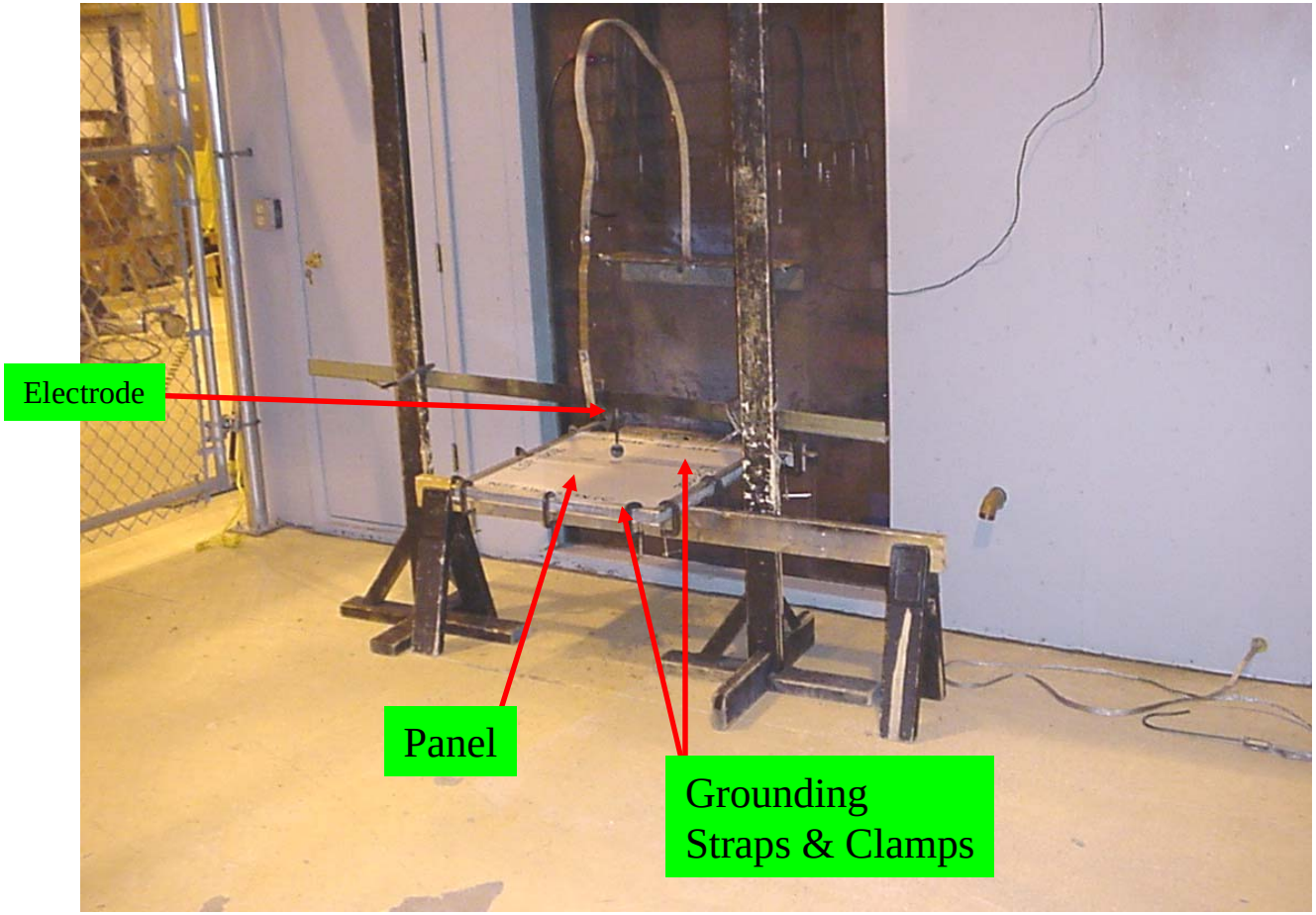
A component -	Peak Amplitude of 200kA Action Integral of 2.5 X 10E6 Amps-squared-sec
B component -	Peak Amplitude of 2kA Maximum Charge Transfer of 10 coulombs
C component -	Average Amplitude of 500 A Maximum Charge Transfer of 20 coulombs

Zone 1B :

A component -	Peak Amplitude of 200kA Action Integral of 2.5 X 10E6 Amps-squared-sec
B component -	Peak Amplitude of 2kA Maximum Charge Transfer of 10 coulombs
C component -	Average Amplitude of 500A Maximum Charge Transfer of 200 coulombs
D component -	Peak Amplitude of 100kA Action Integral of .25 X 10 E 6 Amps-squared-sec

Baseline Configuration:



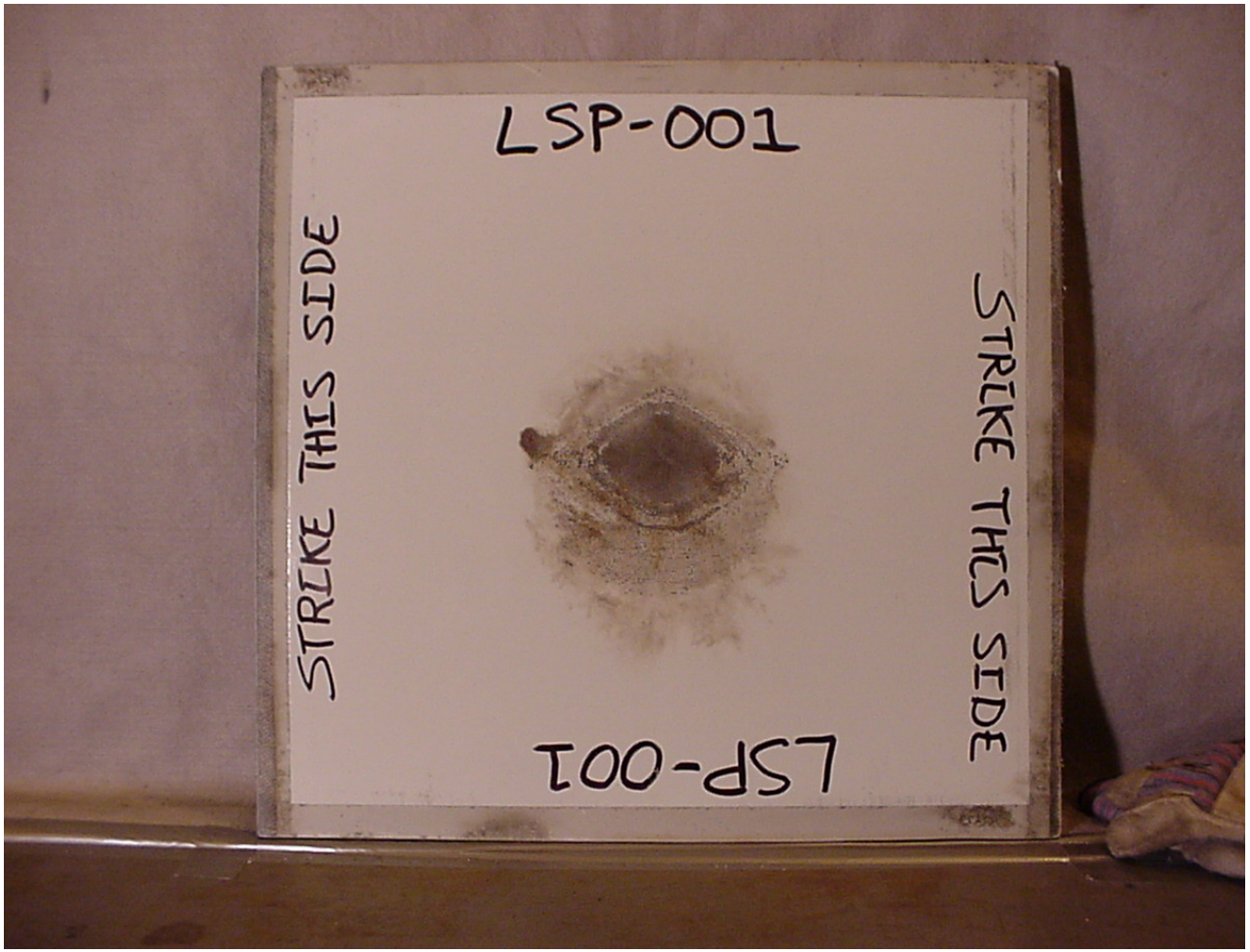


Typical Test Set-up, All Panels

1/8 Korex
Al Mesh
S-2 Glass

Before Zone 1A strike

1/8 Korex
Al Mesh
S-2 Glass



After Zone 1A strike – LSP-001

1/8 Korex
Al Mesh
S-2 Glass

Damage size
Is 3-4 inches,
Damage depth
Limited to
Outside mesh
ply and paint.

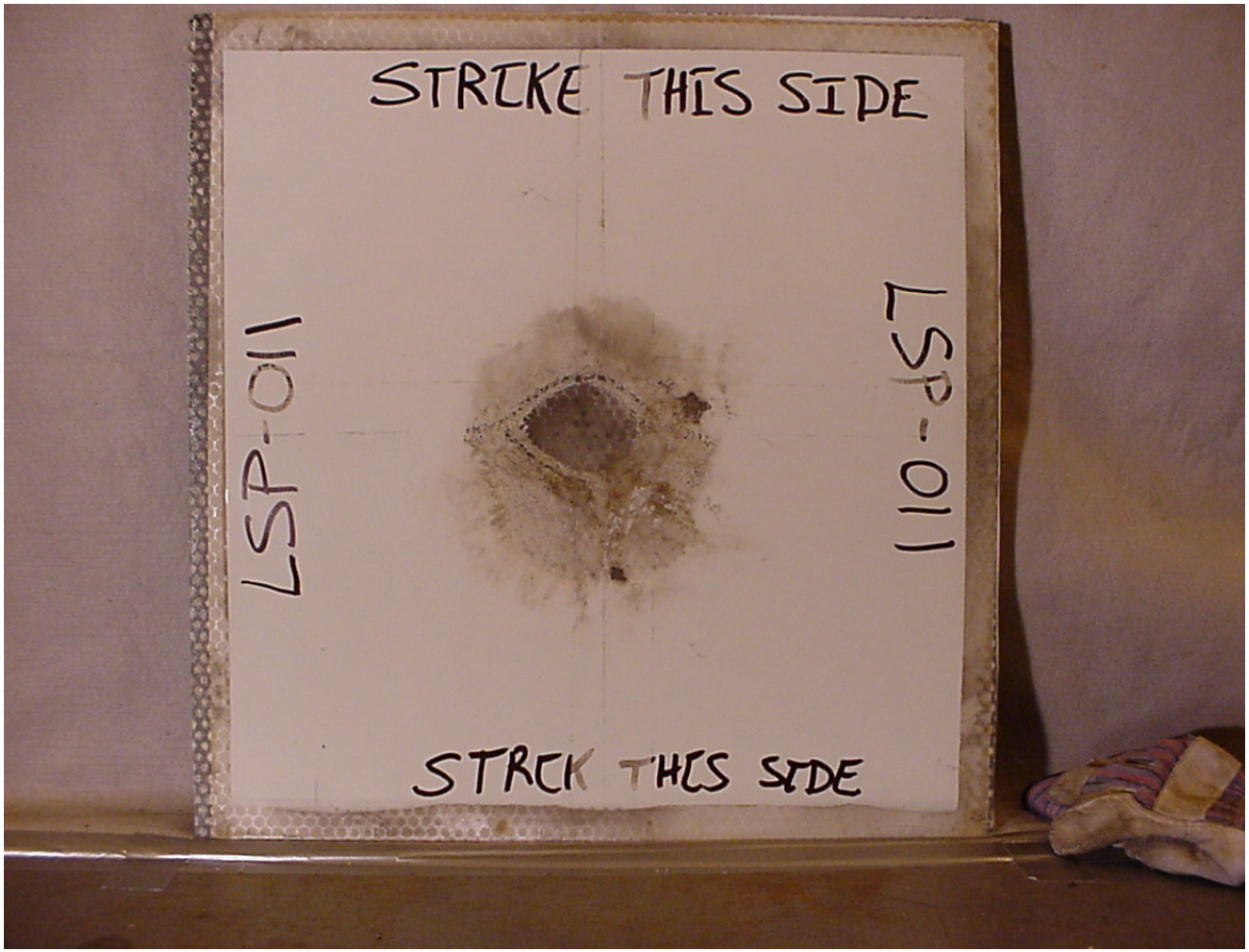
Close-up of LSP-001

1/8 Korex
No Mesh
No Glass

Resultant
damage
punctured
both facings
with considerable
damage to core
-punched
a “thru hole”
all the way through
this 1 inch panel.
damage size 9 inches
in any one direction.

LSP-026, identical to 001, except no protection

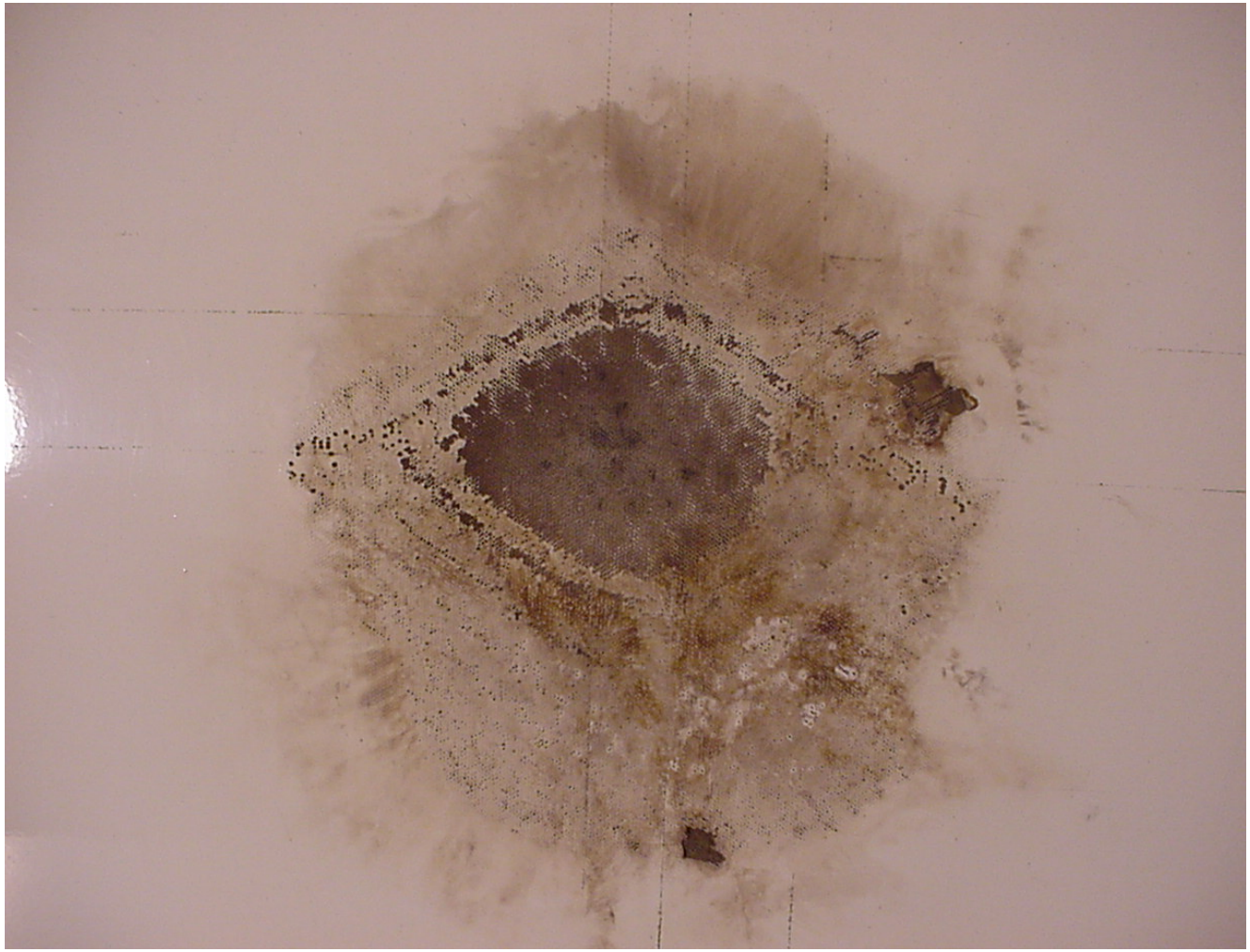
3/8 HRP
Al Mesh
S-2 Glass



After Zone 1A strike – LSP-011

3/8 HRP
Al Mesh
S-2 Glass

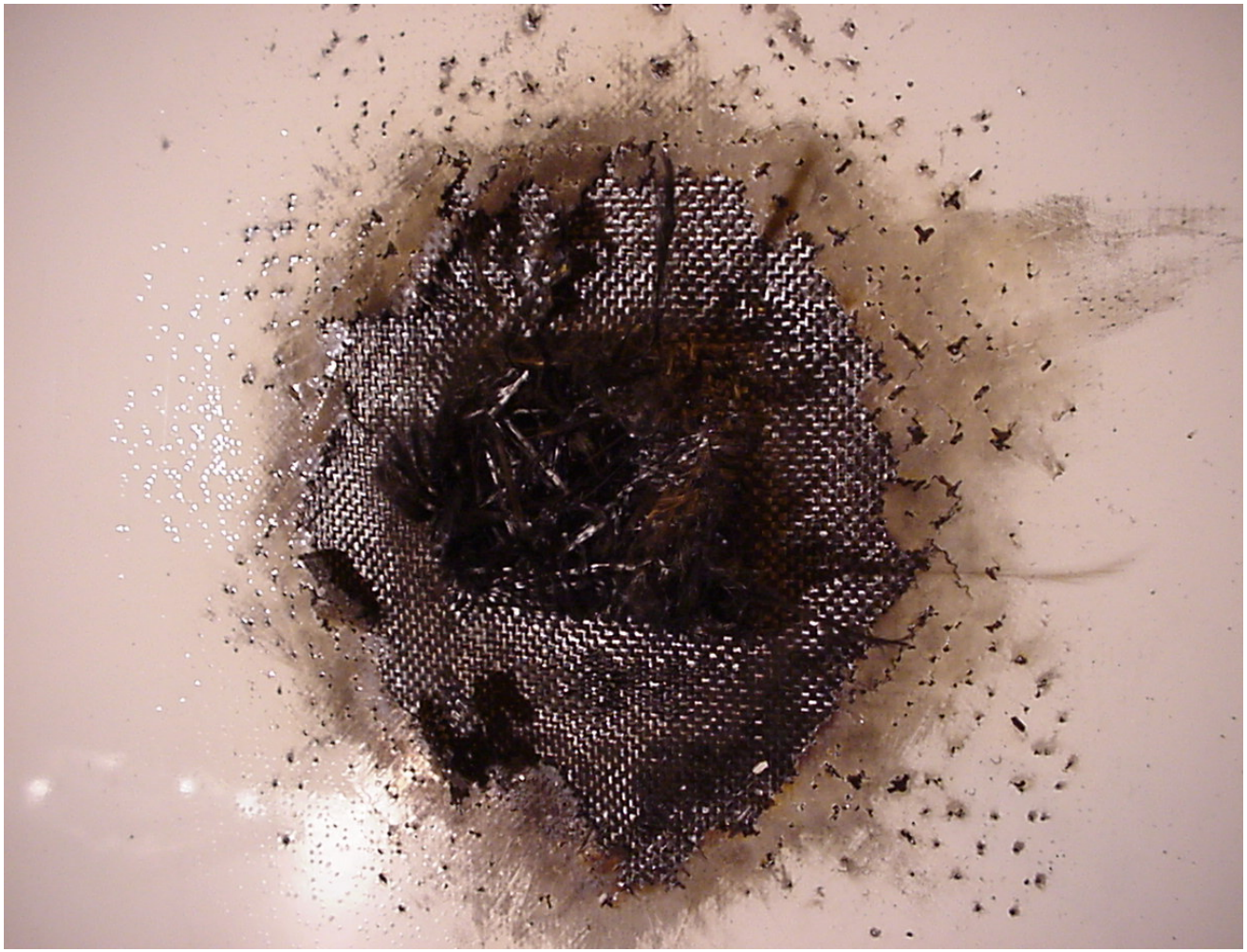
Damage size is 3-4 inches, damage depth limited to outside mesh ply and paint.



Close-up of LSP-011 - Protected

3/8 HRP
No Mesh
No Glass

Resultant damage punctured both facings with considerable damage to core -punched a “thru hole” all the way through this 1 inch panel, damage size 8 inches in any one direction.



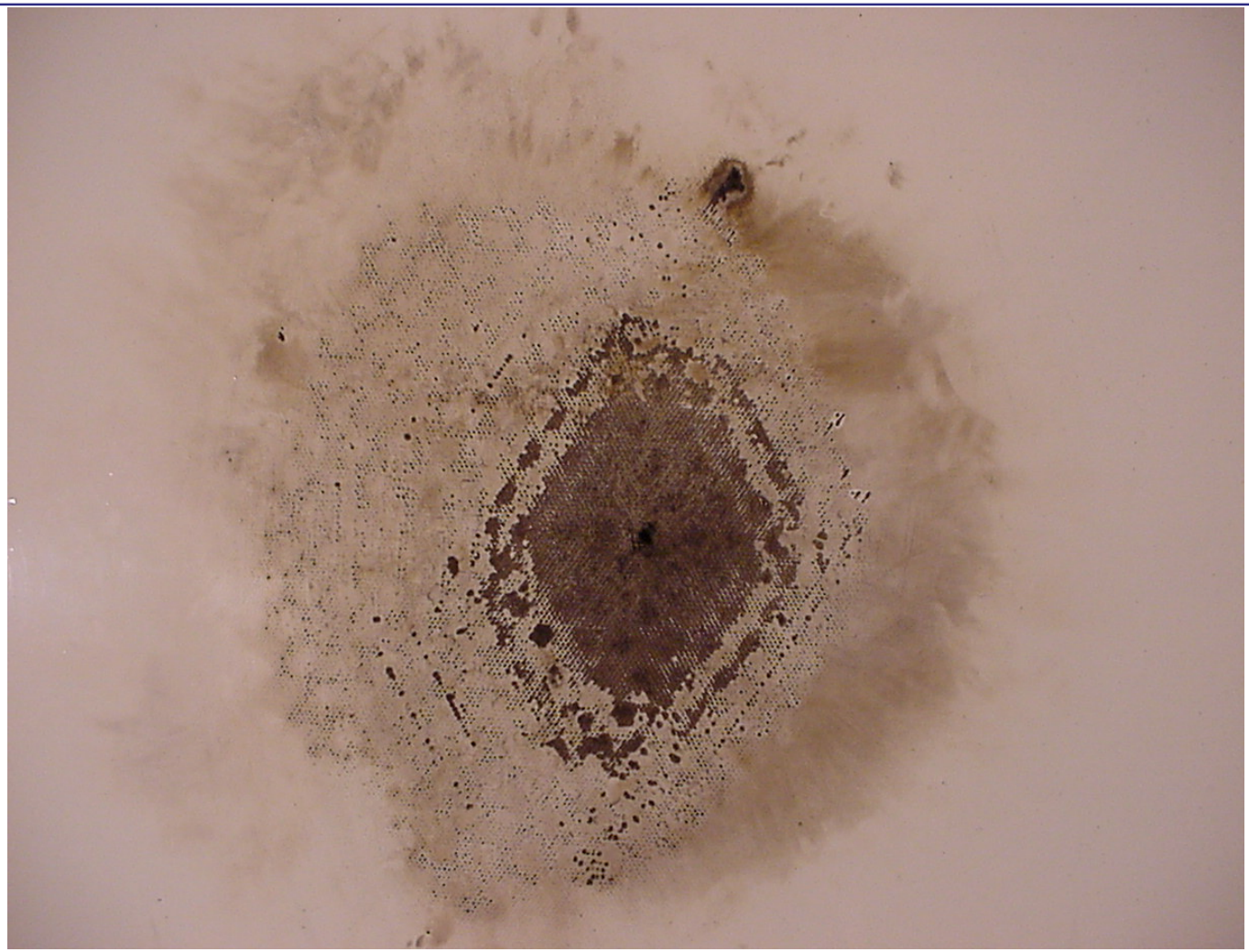
Close-up of LSP-027, identical to 011 except No Protection

3/8 PAA
Al Mesh
S-2 Glass

LSP-020, Aluminum Core, with protection, after Zone 1A strike

3/8 PAA
Al Mesh
S-2 Glass

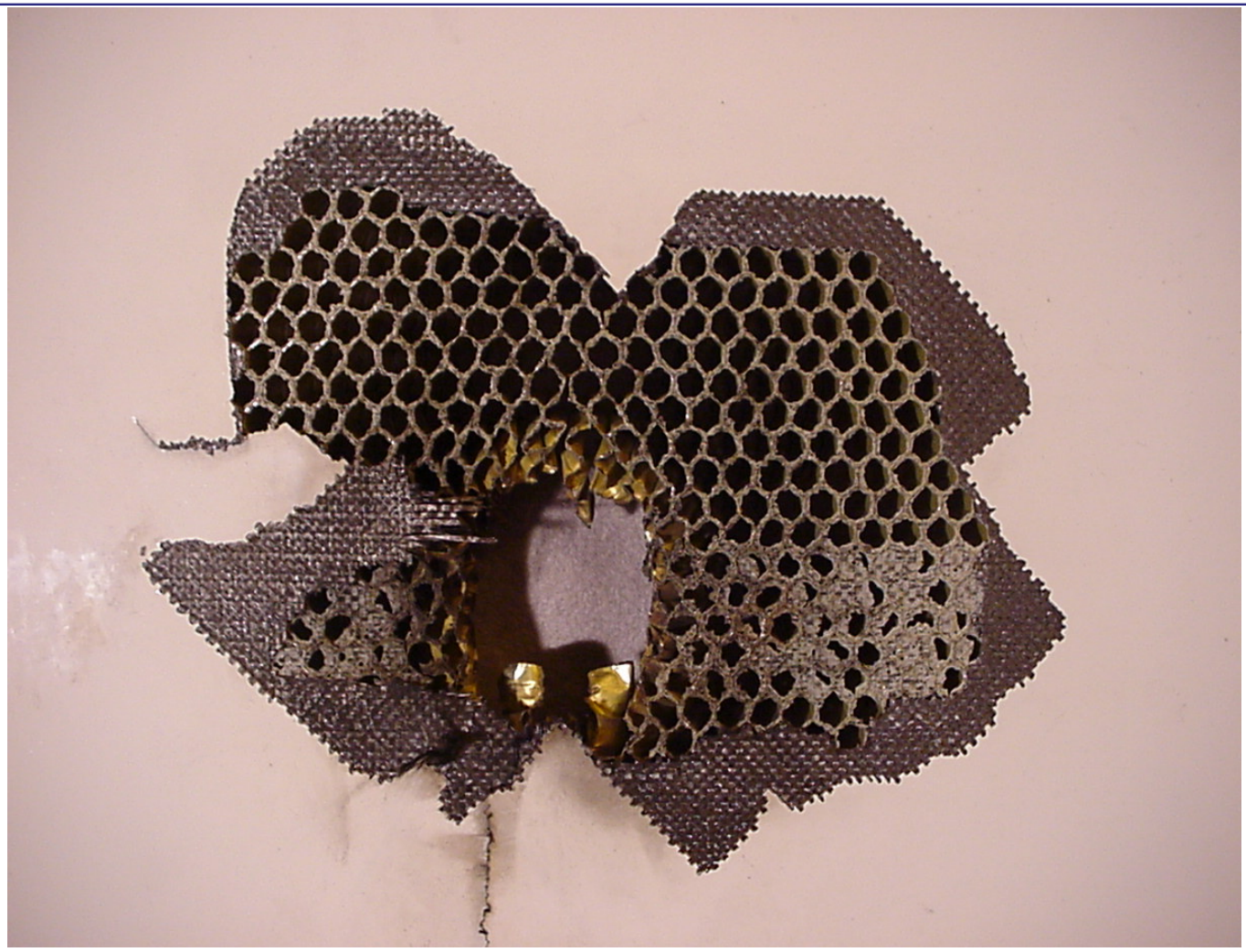
Damage size of this panel was consistent with all other protected panels, 3-4 inches.



Close-up of LSP-020 after Zone 1A strike

3/8 PAA
No Mesh
No Glass

Extensive damage to unprotected aluminum core panel with both facings obliterated and large chunk of core melted – entire panel is delaminated with noticeable "bend" in panel.



LSP-013, Aluminum core, no protection, after Zone 1A strike

1/8 Korex
Al Mesh
S-2 Glass

LSP-022, 0.5 inch thick Arimid core, after Zone 1A strike – nearly identical damage size and shape to 1 inch thick Zone 1A panels.

3/8 HRP
Al Mesh
S-2 Glass

LSP-024, 0.5 inch thick, HRP core, with protection – identical to other Zone 1A strikes

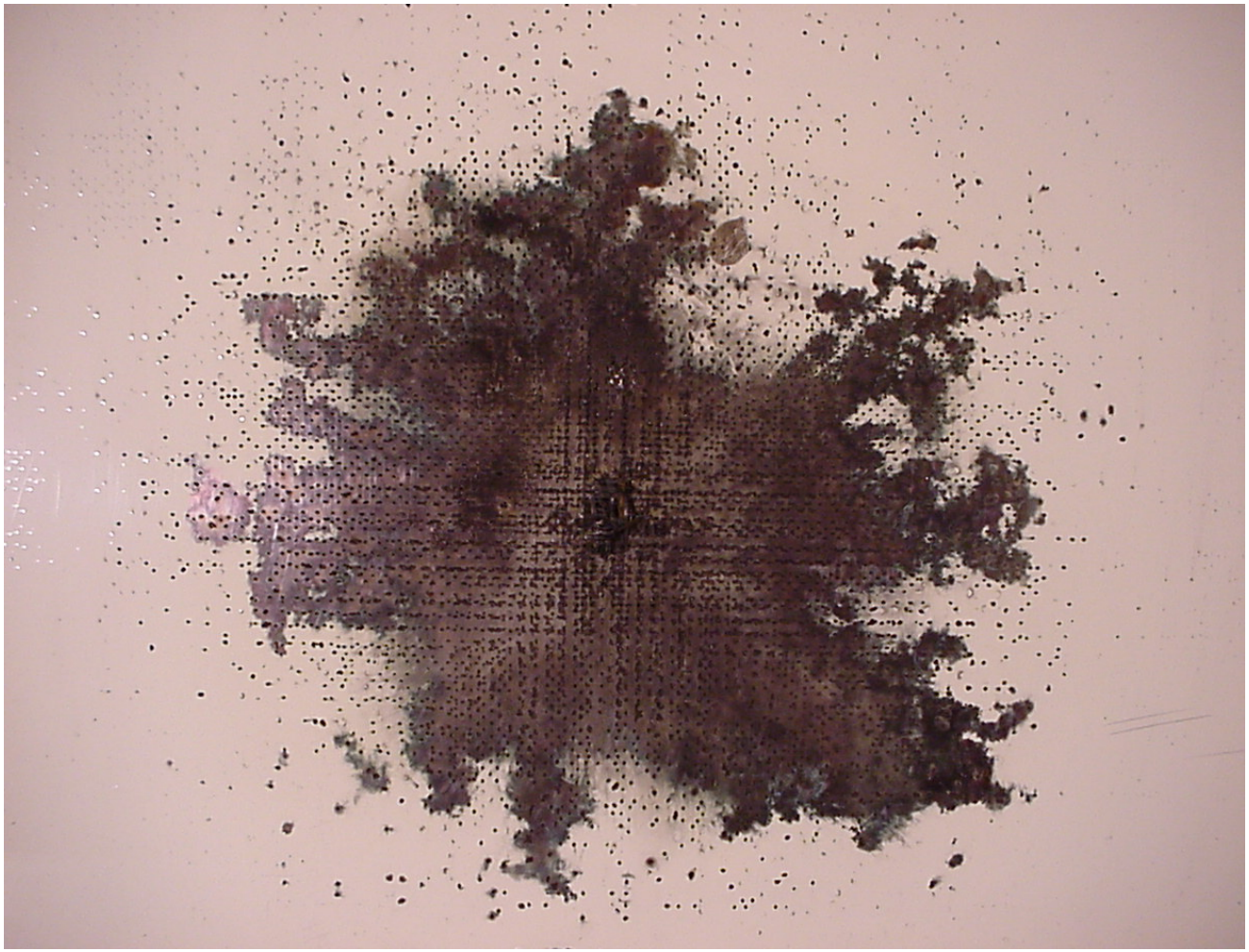
J.M. Welch 5/7/2007

1/8 Korex
Phos-Bronze
No Glass

LSP-009, Interwoven Phos-Bronze mesh, Aramid core, after Zone 1A strike

1/8 Korex
Phos-Bronze
No Glass

Damage
Size extends
9 inches in any
one direction,
burn through
down to core
includes carbon
plies – note
interwoven mesh
damaged all the
way to panel
periphery similar
to detonation
chord over amp
response, i.e
little burrs
of interwoven
wire stick up thru
panel all over.



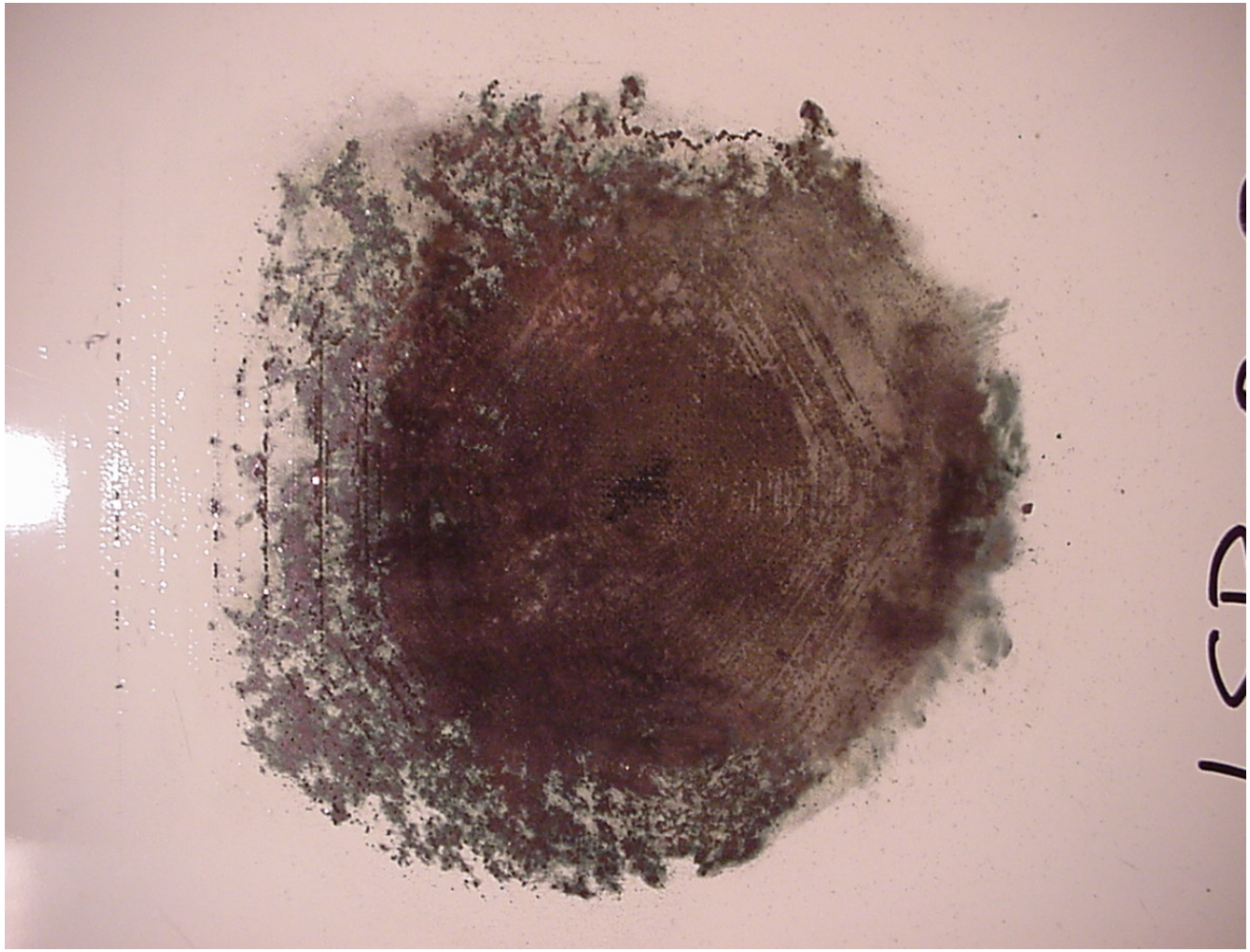
Close-up of LSP-009 after Zone 1A strike

1/8 Korex
Cu Mesh
No Glass

LSP-008, Copper mesh, aramid core, after Zone 1A strike

1/8 Korex
Cu Mesh
No Glass

Damage size
10-14 inches,
Burn through down
To the core, damage
Extends through all
Carbon plies, with
Damage to core as
Well.



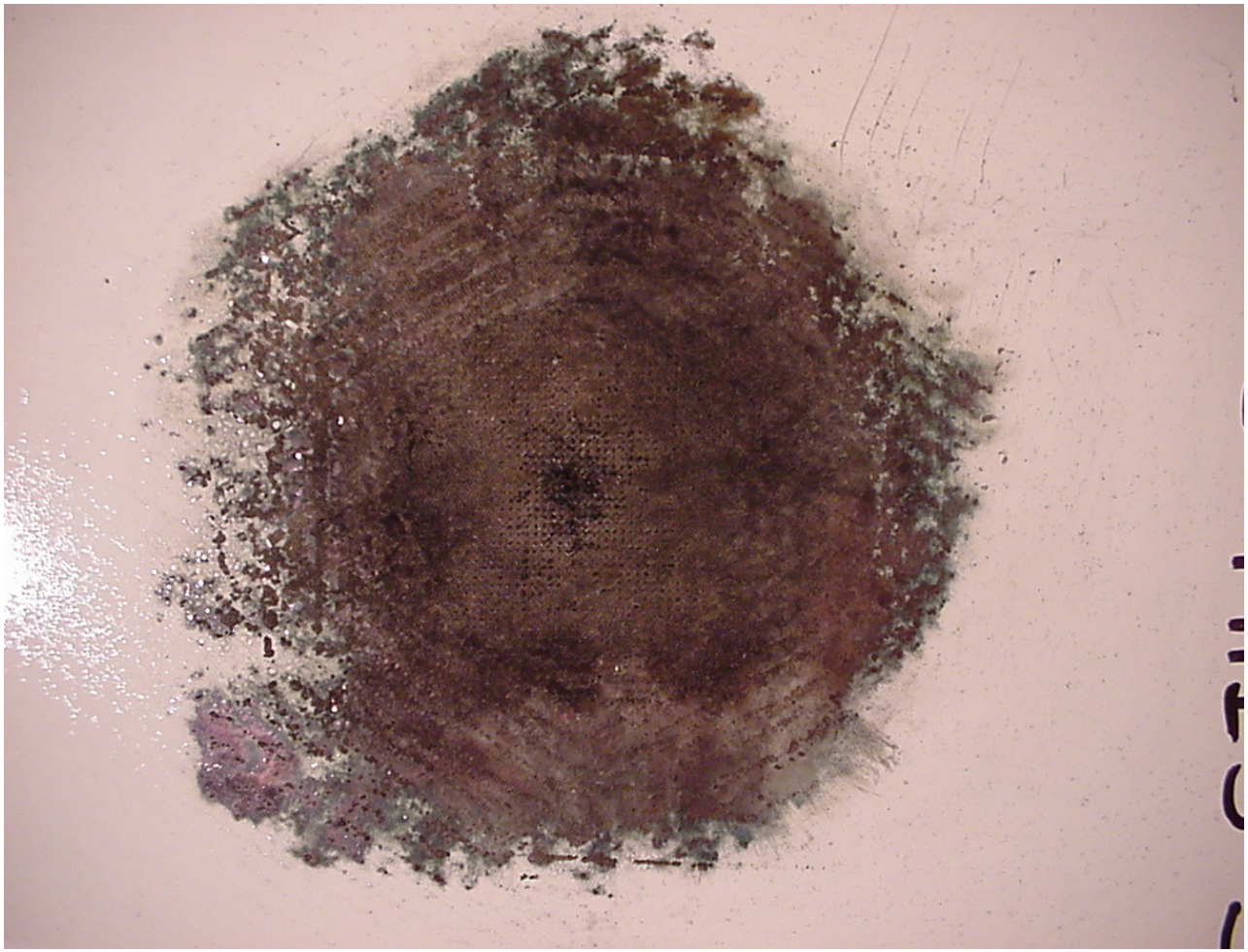
Close-up of LSP-008 after Zone 1A strike

3/8 HRP
Cu Mesh
No Glass

LSP-018, copper mesh, HRP core, after Zone 1A strike

3/8 HRP
Cu Mesh
No Glass

Damage size is 9-12 inches with damage penetrating into the carbon plies all the way down to the core.



Close-up of LSP-018, after Zone 1A strike

1/8Korex
Al Mesh
S-2 Glass
Butt Splice

3-4 inch
Damage zone
Limited to outer
Mesh ply.

LSP-010, after Zone 1A strike

1/8 Korex
Al Mesh
S-2 Glass

Damage size consistent with other protected panels using aluminum mesh 3-4 inches, mesh is only laminate damaged, no carbon plies were impacted.

Panel 009, butt splice using aluminum mesh

1/8 Korex
Al Mesh
S-2 Glass

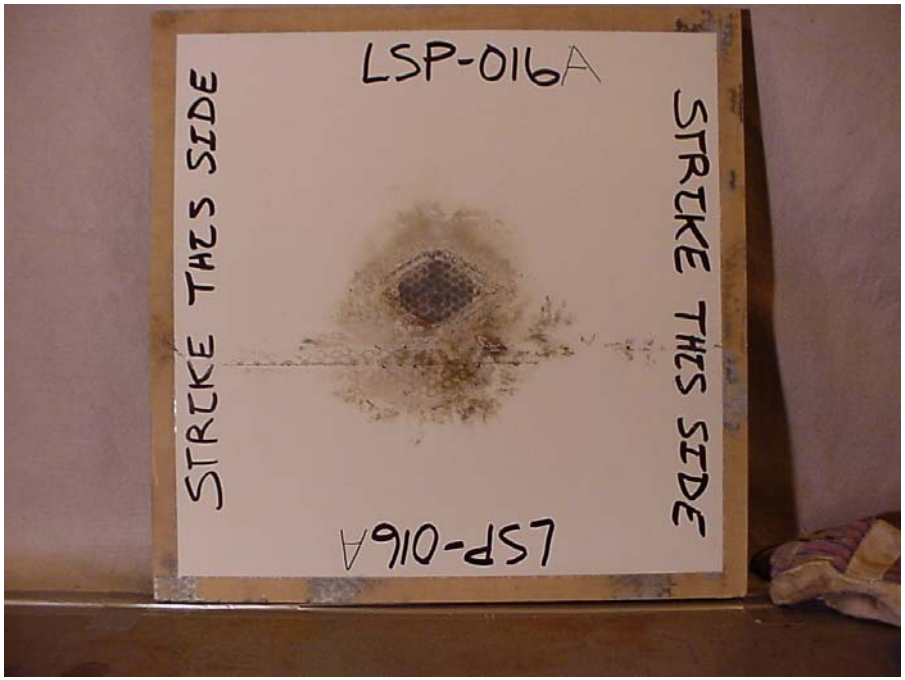
3-4 inch damage, mesh only

5-6 inch damage, mesh only

Zone 1A on left, Zone 1B on right, panel 007 using aluminum mesh protection

3/8 HRP
Al Mesh
S-2 Glass

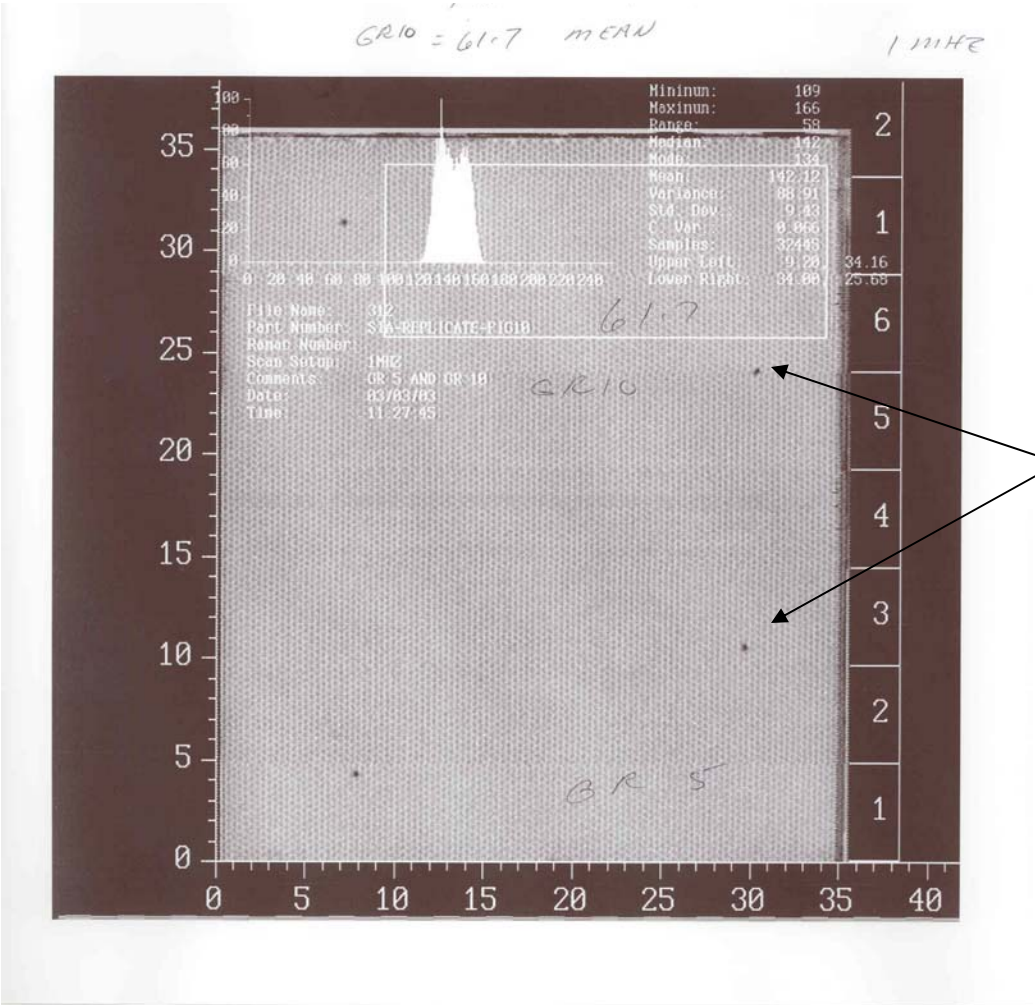
3-4 inch damage, mesh only



5-6 inch damage, mesh only

Zone 1A on left, Zone 1B on right, panel 016 using aluminum mesh protection

NDI Results



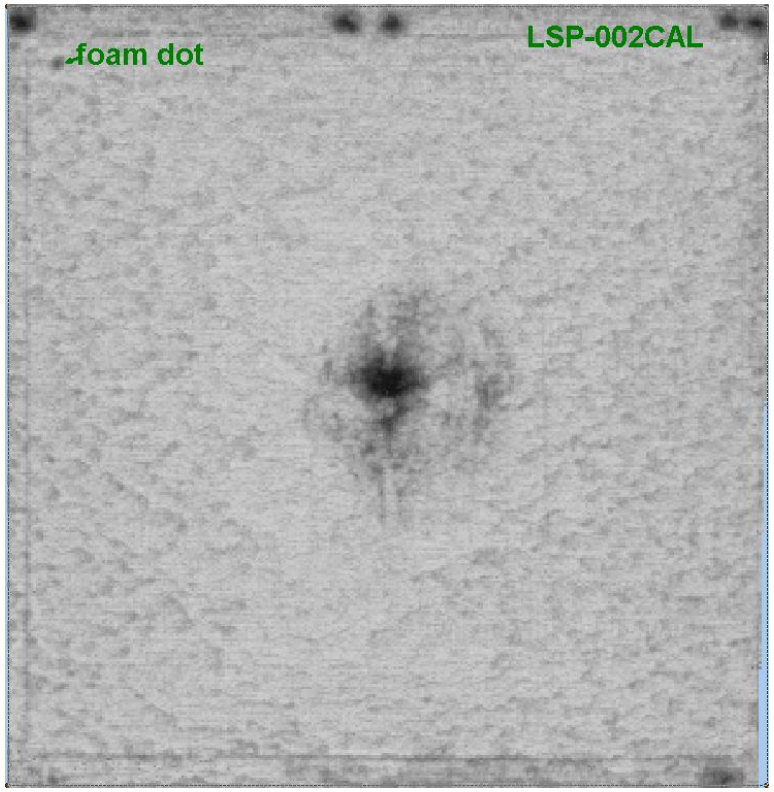
Calibration Tabs

Typical NDI scan of 2’ x 2’ panels – nearly identical for all types – no descrepancies

1/8 Korex
Al Mesh
S-2 Glass

3-4 inch damage, mesh only - visual

1-2 inch damage, mesh only
–validated via TTU (NDI)



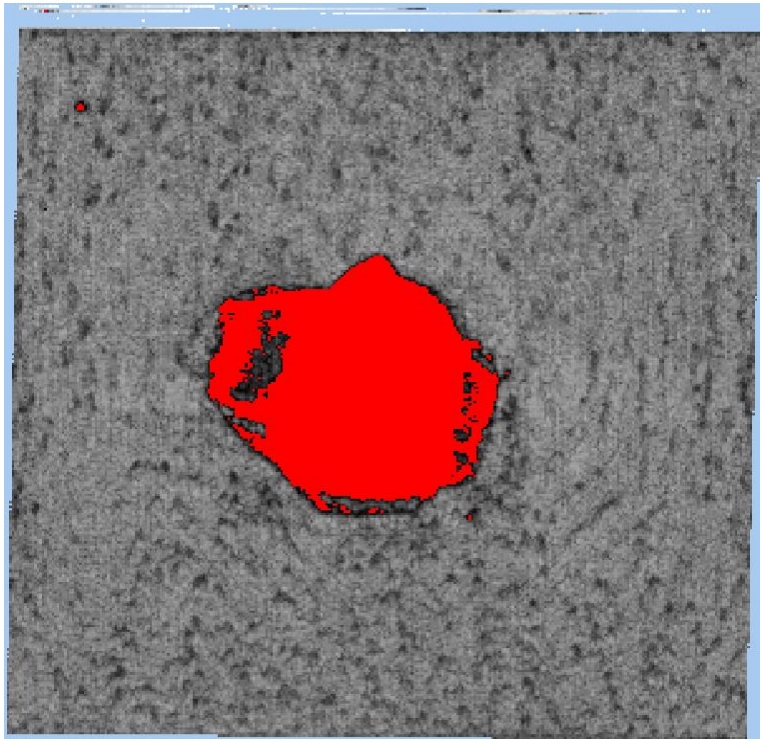
Visual damage of LSP-001, LSP-001 TTU scan on right

Note that NDI documented damage is slightly smaller than mesh burn area

1/8 Korex
No Mesh
No Glass

7-9 inch damage, thru hole - visual

Damage area 12 inches, plus thru hole – Validated by TTU

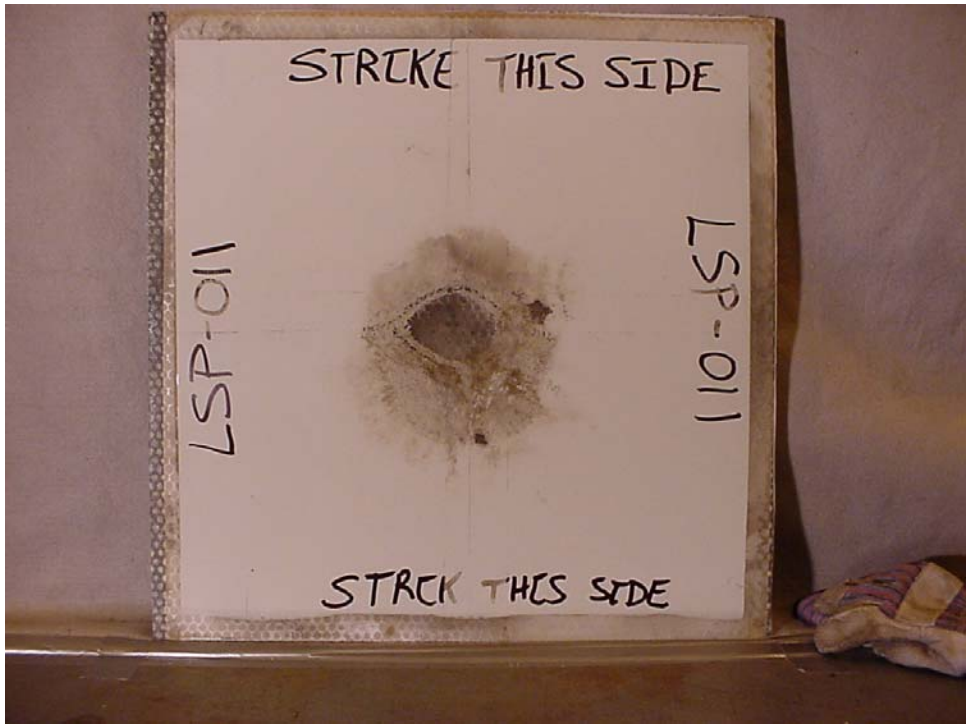


Visual damage of LSP-026, LSP-011 TTU scan on right

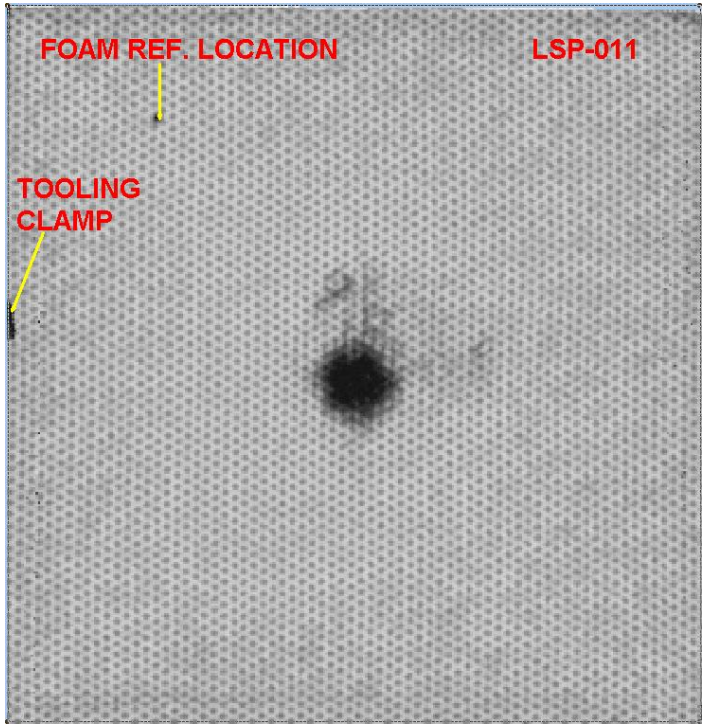
Note that NDI documented damage is larger than visual damage on unprotected panel

3/8 HRP
Al Mesh
S-2 Glass

3-4 inch damage, mesh only - visual



Just under 3 inch damage, mesh only – Validated by TTU



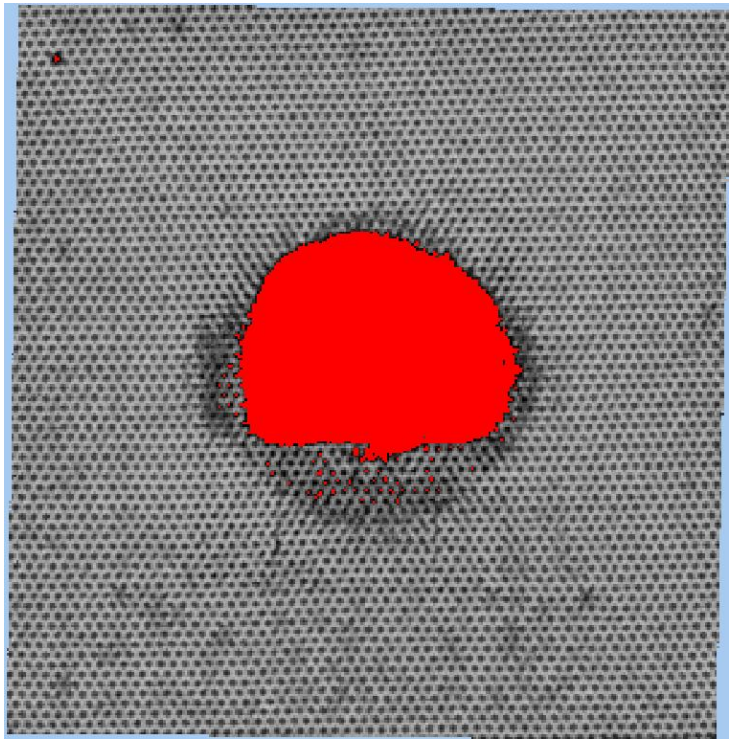
Visual damage of LSP-011, LSP-011 TTU scan on right

Note that NDI documented damage is slightly smaller than mesh burn area

3/8 HRP
No Mesh
No Glass

8 inch DIA damage, thru hole - visual

Damage area 10 inches, plus thru hole – Validated by TTU



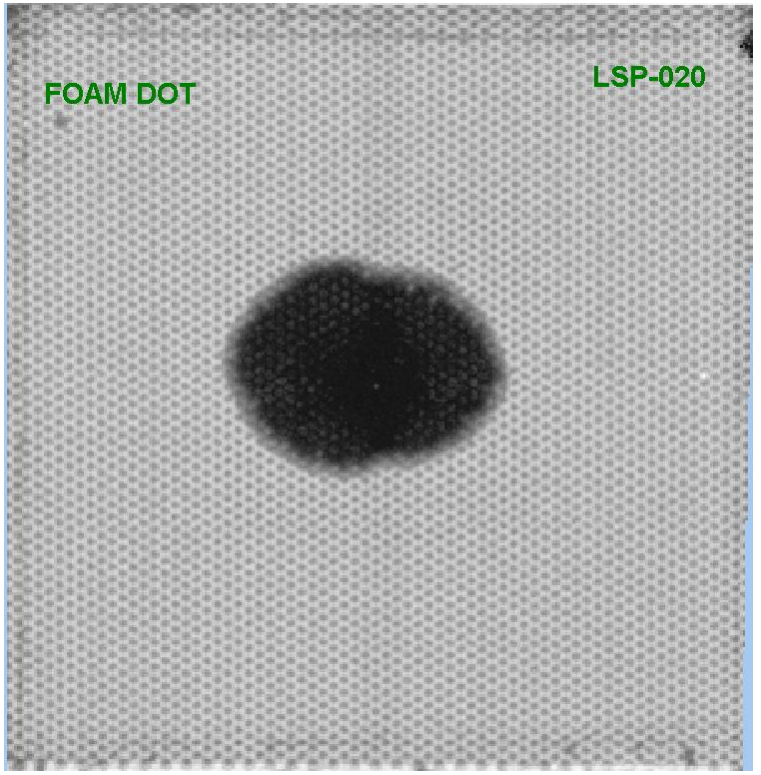
Visual damage of LSP-027, LSP-027 TTU scan on right

Note that NDI documented damage is larger than visual damage on unprotected panel

3/8 Al-PAA
Al Mesh
S-2 Glass

6-7 inch DIA damage, mesh and 1-2 plies - visual

Damage area 10 inches, dis-bonded from core – Validated by TTU



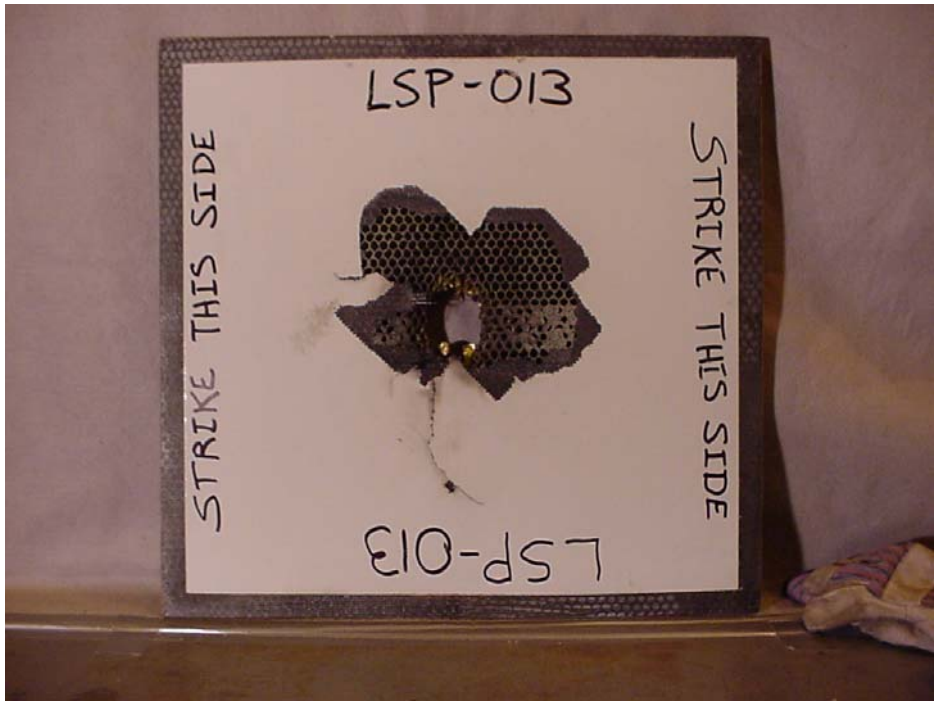
Visual damage of LSP-020, LSP-020 TTU scan on right

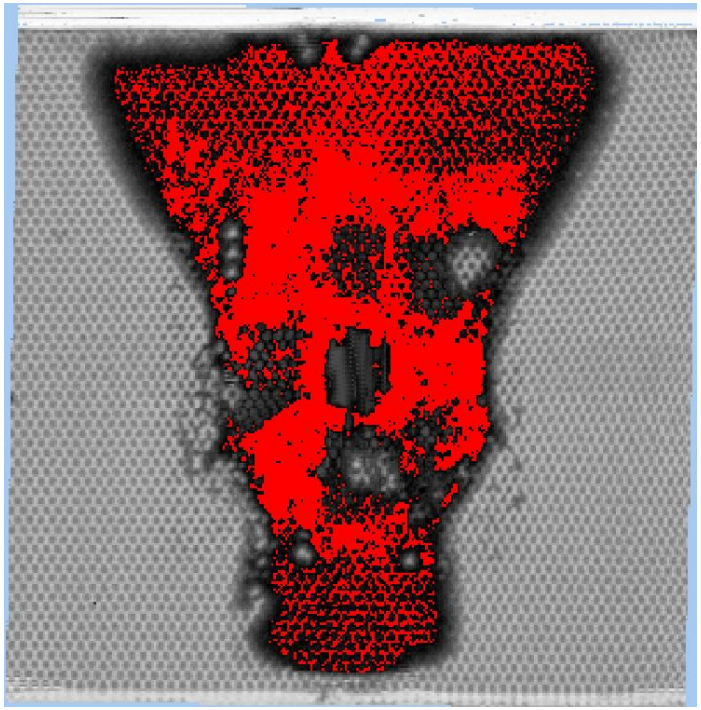
Note that NDI documented damage is larger than visual damage on protected aluminum core panel

3/8 PAA
No Mesh
No Glass

12-14 inch DIA, panel split, large area - visual

Damage area entire panel destroyed – Validated by TTU





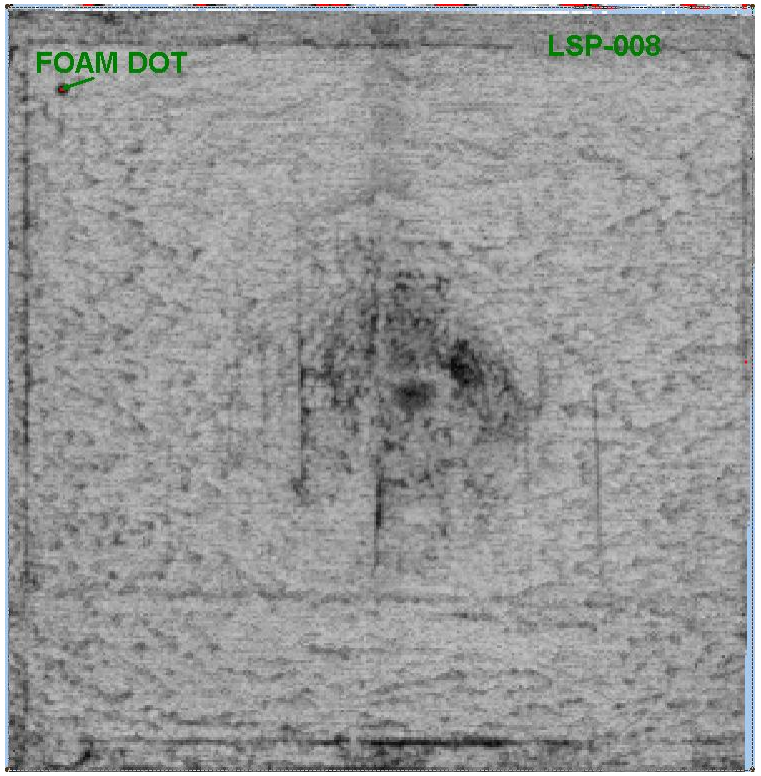
Visual damage of LSP-013, LSP-013 TTU scan on right

Note that NDI documented damage is much larger than visual damage on unprotected aluminum core panel

1/8 Korex
Cu Mesh
No Glass

12-14 inch DIA, Outer 1-2 plies
- visual

Damage area 11 inch DIA 1-2 ply–
Validated by TTU



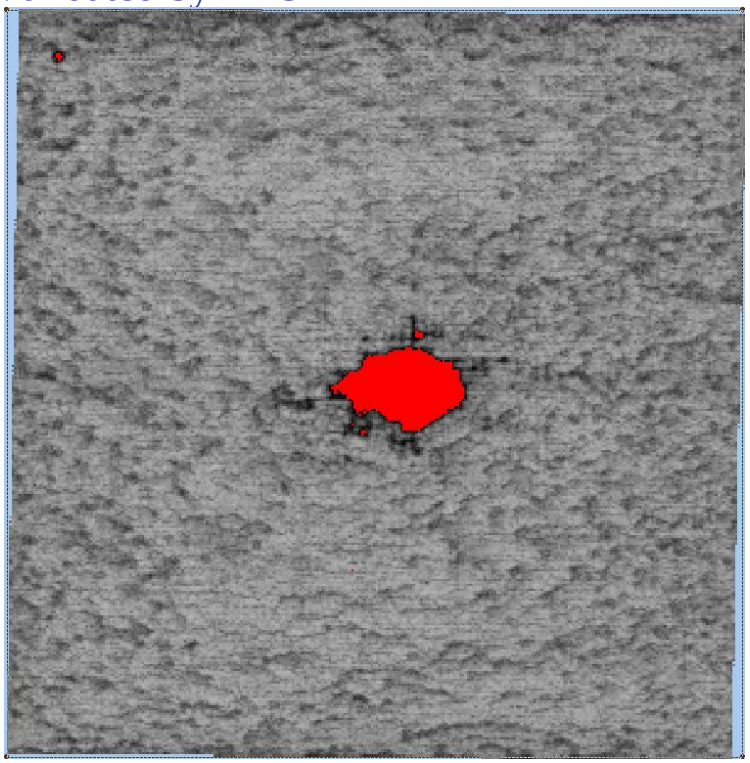
Visual damage of LSP-008, LSP-008 TTU scan on right
Note that NDI documented damage is much larger than visual damage on copper mesh protected panel,
Attenuation “streaks” running vertical will have to be addressed in repair……

J.M. Welch 5/7/2007

1/8 Korex
Phos-Bronze Mesh
No Glass

9-11 inch DIA, Outer 1-2 plies
- visual

Damage area 9 inch DIA 1 ply– dis-bonded
From core at center 4-5 inch DIA
Validated by TTU



Visual damage of LSP-009, LSP-009 TTU scan on right

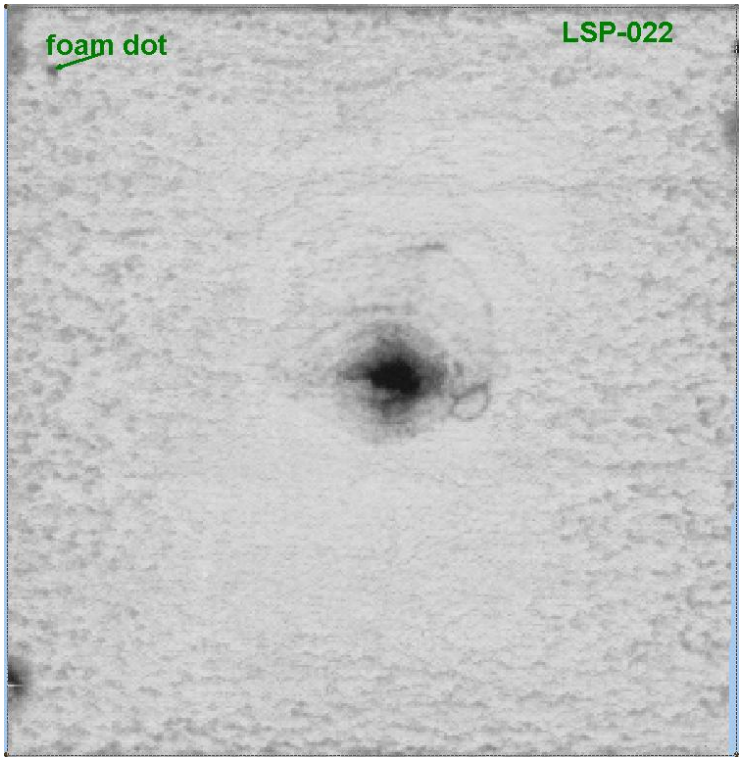
Note that NDI documented damage is “deeper into the thickness” than visual damage on Phos-Bronze protected panel……note spotted attenuation representing “detonation chord” effect….

J.M. Welch 5/7/2007

1/8 Korex (0.5 inch thk)
Al Mesh
S-2 Glass

3-4 inch DIA, mesh only
- visual

Damage area 2 inch DIA, mesh only-
Validated by TTU



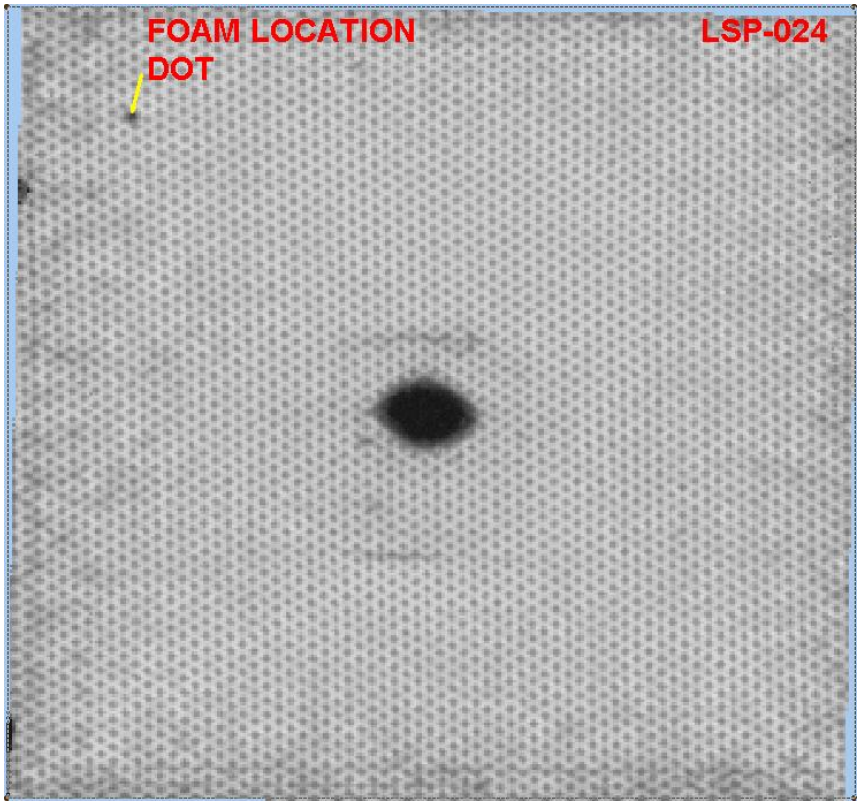
Visual damage of LSP-022, LSP-022 TTU scan on right

Note that NDI documented damage is less than visual damage on Al mesh protected 0.50 inch thick panel……

3/8 HRP (0.5 inch thk)
Al Mesh
S-2 Glass

3-4 inch DIA, mesh only
- visual

Damage area 2 inch DIA, mesh only-
Validated by TTU



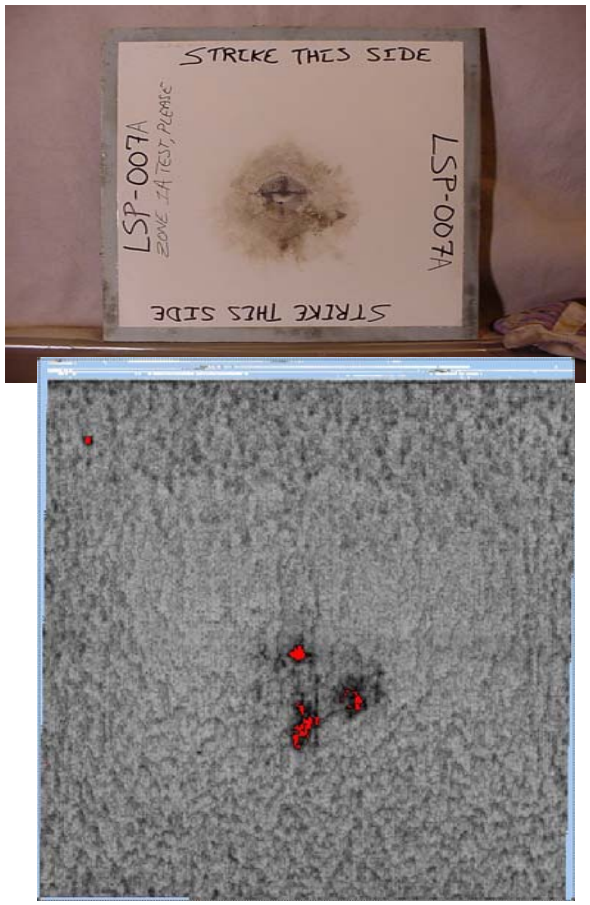
Visual damage of LSP-024, LSP-024 TTU scan on right

Note that NDI documented damage is less than visual damage on Al mesh protected 0.50 inch thick panel……

J.M. Welch 5/7/2007

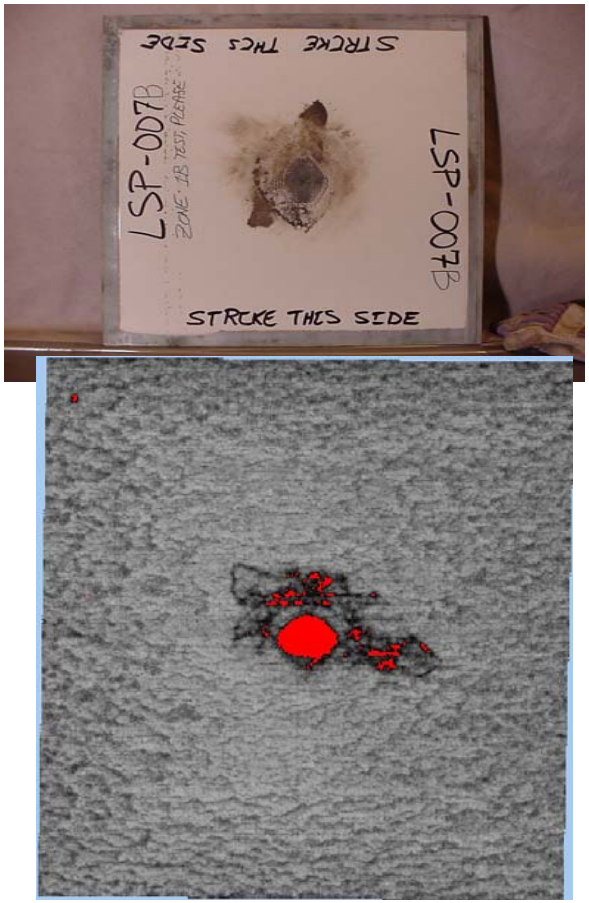
1/8 Korex
Al Mesh
S-2 Glass

3-4 inch damage, mesh only - visual



1-2 inch locations – validated by TTU

5-6 inch damage, mesh only - visual

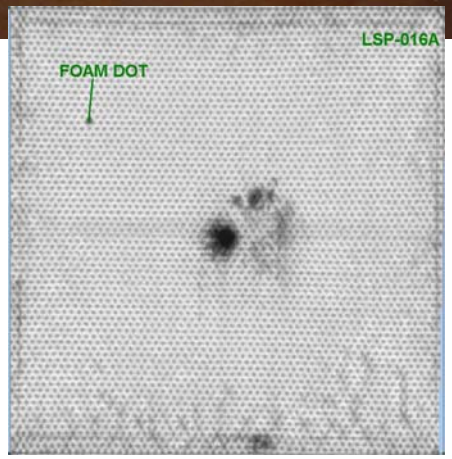


2-3 inch DIA locations – validated by TTU

Zone 1A on left, Zone 1B on right, panel 007 using aluminum mesh protection

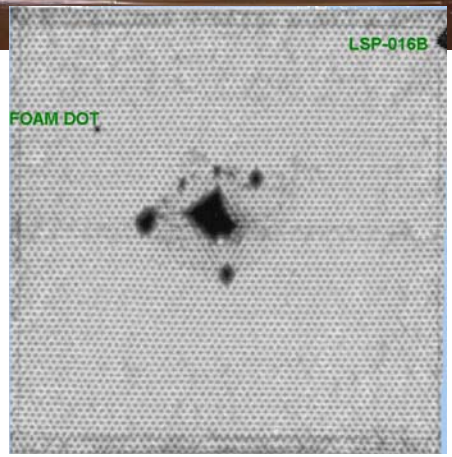
3/8 HRP
Al Mesh
S-2 Glass

3-4 inch damage, mesh only



1-2 inch locations – validated by TTU

5-6 inch damage, mesh only



2-3 inch DIA locations – validated by TTU

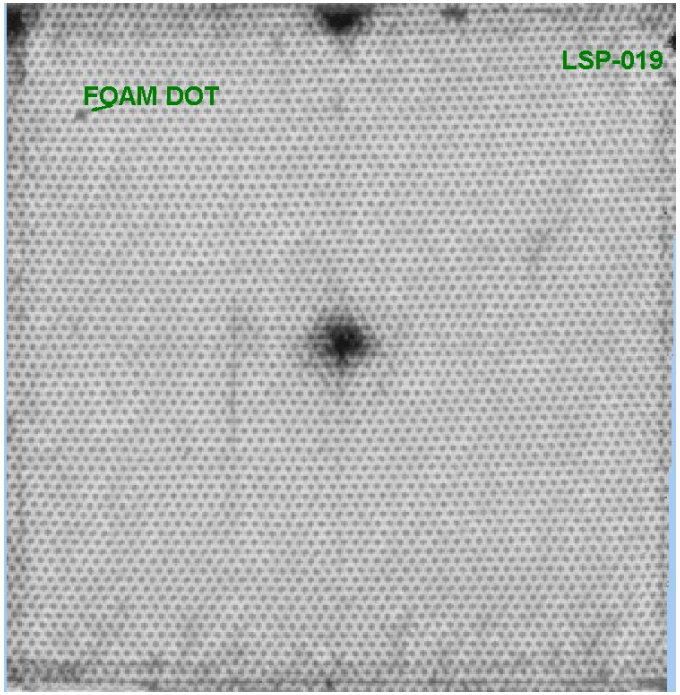
Zone 1A on left, Zone 1B on right, panel 016 using aluminum mesh protection

J.M. Welch 5/7/2007

3/8 HRP (1.0 inch thk)
Al Mesh – Butt spliced
S-2 Glass

3-4 inch DIA, mesh only
- visual

Damage area 1-1.5 inch DIA, mesh only-
Validated by TTU



Visual damage of LSP-019, LSP-019 TTU scan on right

Note that NDI documented damage is the least amount, all panels, for this configuration…..

Conclusions from Testing for Lightning Strike: (Zone 1A and 1B Tested)

Protected panels using any type of mesh/protection performed infinitely better than non-protected panels.

Aluminum mesh provided smallest damage size and least amount of penetration to substrate plies

Aluminum mesh performed very well in either Zone 1A or 1B testing, 1B damage size was 25% larger, but penetration was the same, i.e. mesh only. Non-Destructive Testing confirmed that what was evident visually, was the damage size in need of repair.

Copper mesh resulted in damage size 3 times larger, with penetration into the substrate plies and damage to the core.

Interwoven Phos-Bronze resulted in damage size a minimum of 2 times larger depending on whether or not you deal with all the broken wires sticking up through the panel all the way to the edge. Plies were also dis-bonded from core in the center of the strike in a 4 inch dimension – i.e. deeper penetration.

Isolation ply types had no effect on aluminum mesh performance, S-2 glass and E-glass performed identically.

Panel thickness had no major effect on "protected" panel types. Visual damage size and depth was nearly identical for 0.5 inch thick panels as it was for 1 inch thick panels. The amount was not significant

Splice configurations had no effect on strike resistance to damage. Butt splices worked as well, if not better than some examples of overlap splice applications.

Aluminum core "unprotected" panels will result in large damage to that type of configuration, however, "protected" with aluminum mesh, aluminum core panels performed with small, manageable damage size areas, just like other non-metallic core panels.

Process for Applying Damage Prevention Kit:

Sample Panel is prepared and marked with locating templates – note dark outline of area to be prepared

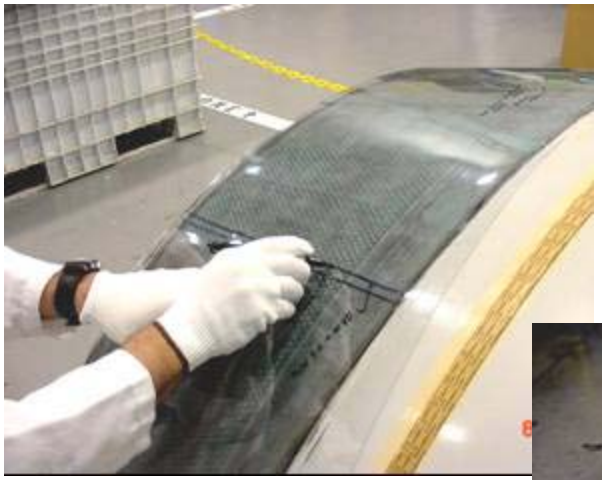
Process for Applying Damage Prevention Kit:

Sanding is performed to the outline to remove all prior paint and surfacer- typical in preparing for a bond event

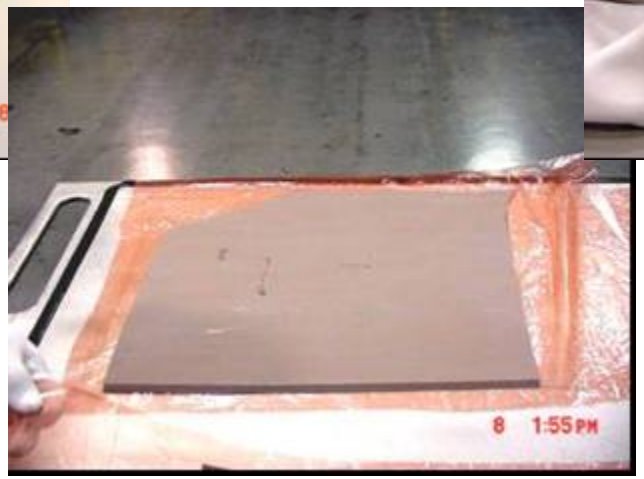
Process for Applying Damage Prevention Kit:

One half of the area is sanded completely.
Note that surface is prepared to avoid sanding into any substrate structures.

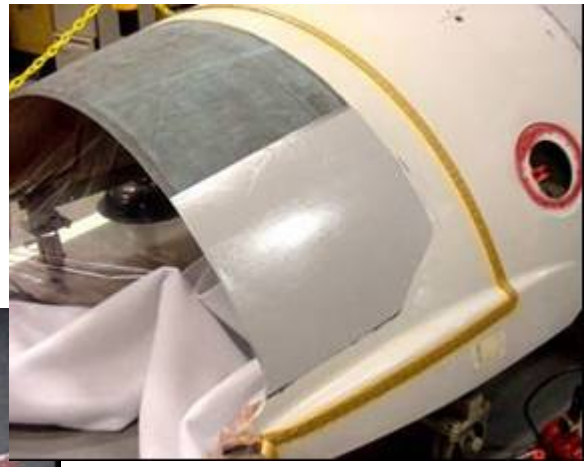
Process for Applying Damage Prevention Kit:



Locating Templates are re-applied to assist lay-up placement



The pre-plied, pre-consolidated mesh/bond materials are extracted from the kit and FEP removed.



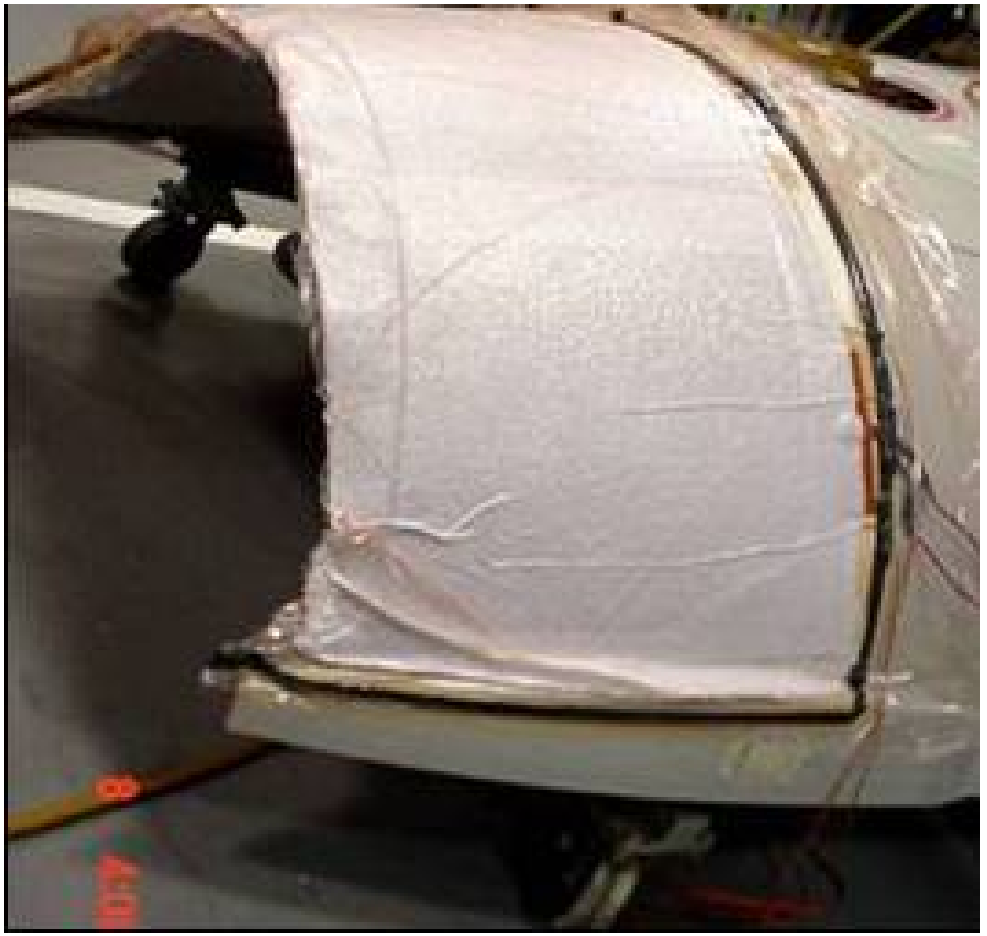
Sample Panel with first kitted materials in place

Process for Applying Damage Prevention Kit:

Sample Panel with mesh/bond materials in place, ready for cure- the process was realized in halves-i.e. lower half of panel prepared and materials placed/bonded, then repeated for upper panel half….

Process for Applying Damage Prevention Kit:

Sample Panel with vacuum bag, heat blanket and thermocouples in place, ready for cure. Insulation was placed around the periphery of heat blanket to ensure no over-heating on part.



Process for Applying Damage Prevention Kit:

Sample Panel after cure and filling operations completed - paint applied. Entire operation occurred inside 8 hour shift. Spirit believes this can be done on, or off wing.

Conclusions – Repair Design, Configured from Test Data

- **The extensive test data for lightning strike damage enabled the configuration of the damage prevention kit. Materials data and panel response were the two key elements learned from the lightning strike testing.**
- **NDI provided further evidence of "performance" of protection methods during a lightning strike event.**
- **The damage prevention kit, applied like a repair, has the ability to quickly apply lightning strike materials to existing products. The proof of concept work on a sample panel provided evidence of the ability to quickly, and capably, apply lightning strike mesh to existing structure-on or off wing.**
- **Spirit continues to work the proof of concept details to perfect the process and repair.**
- **Spirit has created a damage prevention kit of consolidated elements supported by positioning templates and instructions.**
- **The combination of testing, repair design for damage prevention, and thorough understanding of the necessary processes to bond materials to existing structure has provided a solution to known fleet problems surrounding lightning strike damage.**