CSAT Meeting: WPI, Worcester, MA

B1 Bomber-FEB Panel Repair by Cold Spray

Christian Widener, Ph.D.
South Dakota School of Mines and Technology

Rob Hrabe
HF Webster Engineering Services, Inc.

Brian James
Air Force Engineering Technical Services, Ellsworth AFB

Victor Champagne, Ph.D.
Army Research Lab

Repair, Refurbish, and Return to Service

October 30, 2012

Christian.Widener@SDSMT.edu

Project Team

- Repair, Refurbish, and Return to Service Center (R3S) – a SD Governor funded 2010 Center of Excellence at the South Dakota School of Mines and Technology (SDSMT)
  - Director, Christian Widener, Ph.D.
- HF Webster Engineering Services, Inc.
  - Mr. Rob Hrabe
- Air Force Engineering Technical Services – Ellsworth AFB and Ph.D. student SDSMT
  - Mr. Brian James
- Army Research Lab
  - Dr. Victor Champagne
- Life Extension of Navy Weapon Systems Project managed by ACI Technologies, Inc. – Navy Mantech Benchmarking and Best Practices Center
  - Mr. Carmine Meola
  - Ms. Rebecca Morris

Problem Statement

- Aluminum aircraft external access panels are typically secured to the airframe with steel TRIDAIR fasteners.
- The fasteners are designed to sit flush with the panel to enable laminar airflow over the fastener head.
- Repeated access to these panels wears and enlarges the holes in the panel.
- As wear increases, the fastener sits further and further below the surface of the panel, resulting in turbulent airflow, vibration of the panel, and eventual pull through and loss of the fastener in flight…

Christian.Widener@SDSMT.edu

Problem Statement

- Integrally stiffened bonded panel – composite metal hybrid structure
- **Currently, no acceptable permanent repair exists**
- *Furthermore, new repair technologies are not systematically incorporated into maintenance supply processes.*
  - *Organizational barriers prevent implementation of new technology into aging weapon systems*
  - *Very little funding is available for developing repair processes on legacy weapon systems*
- Replacement Cost >$200K each, but parts are not even available…Fleet liability of approx. $50M.

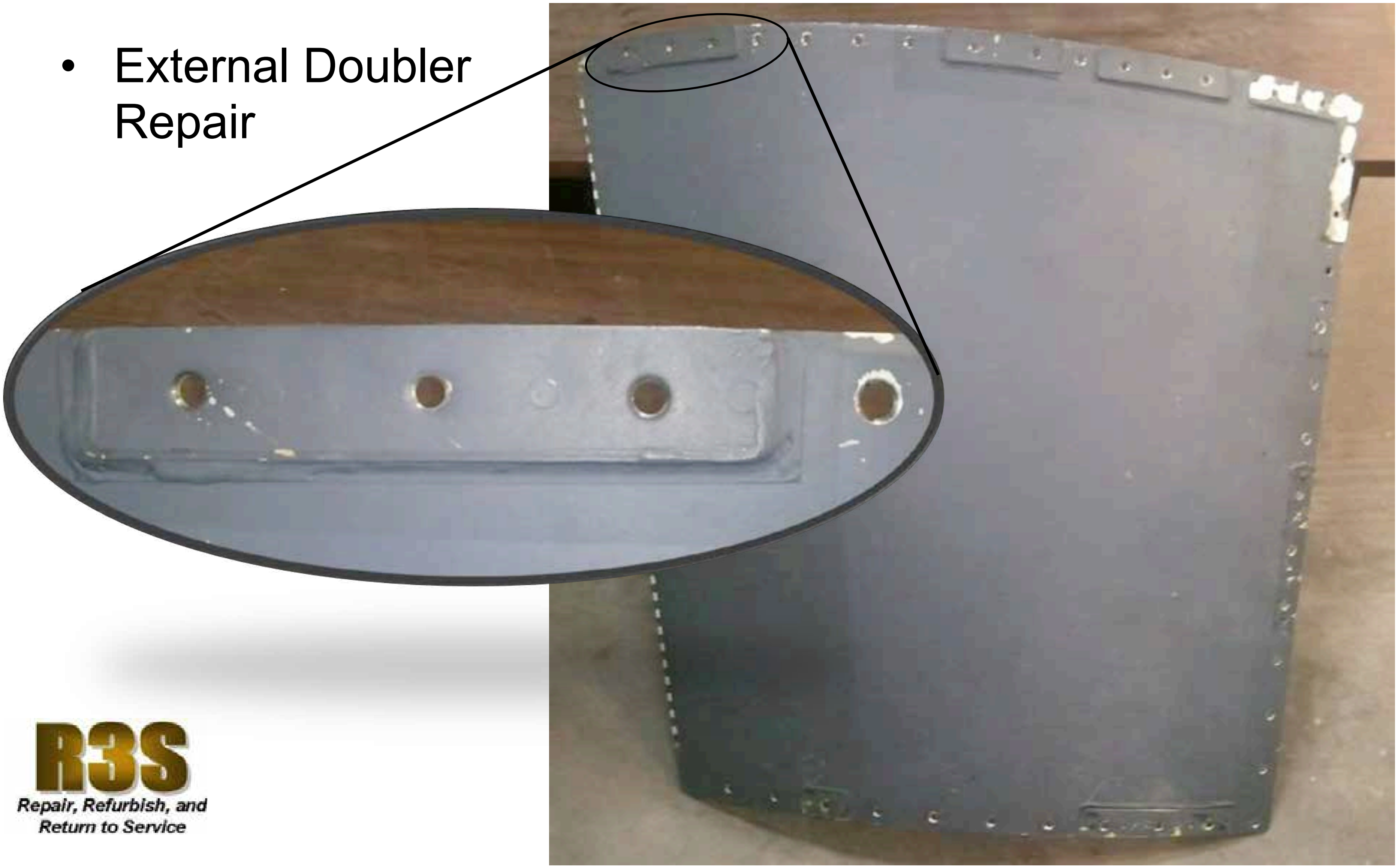
Repair, Refurbish, and Return to Service

A cold spray repair solution has been developed… ROI > 10:1

Christian.Widener@SDSMT.edu

Panel Selected for Refurbishment

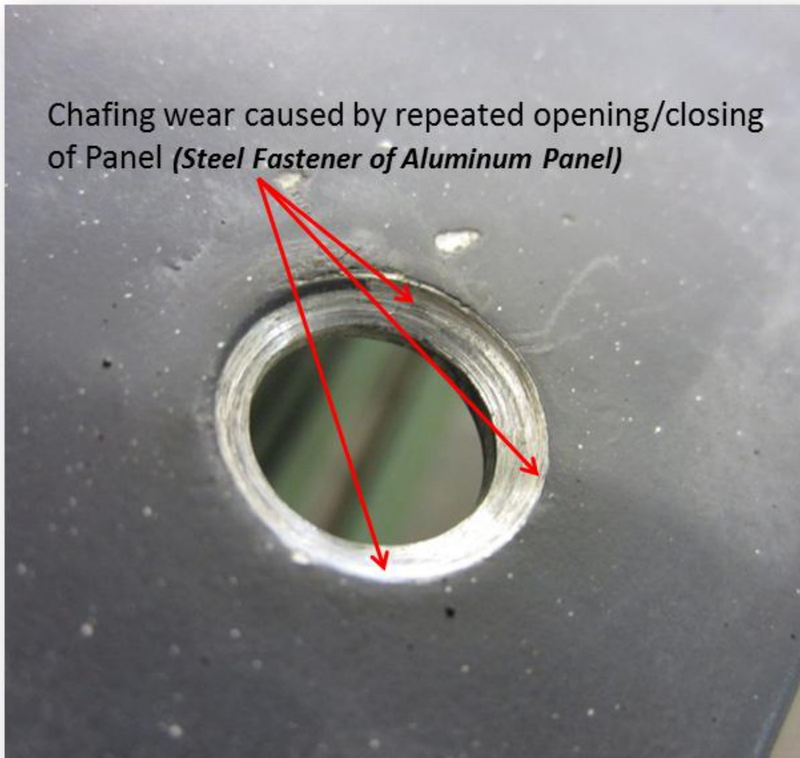
- External Doubler Repair

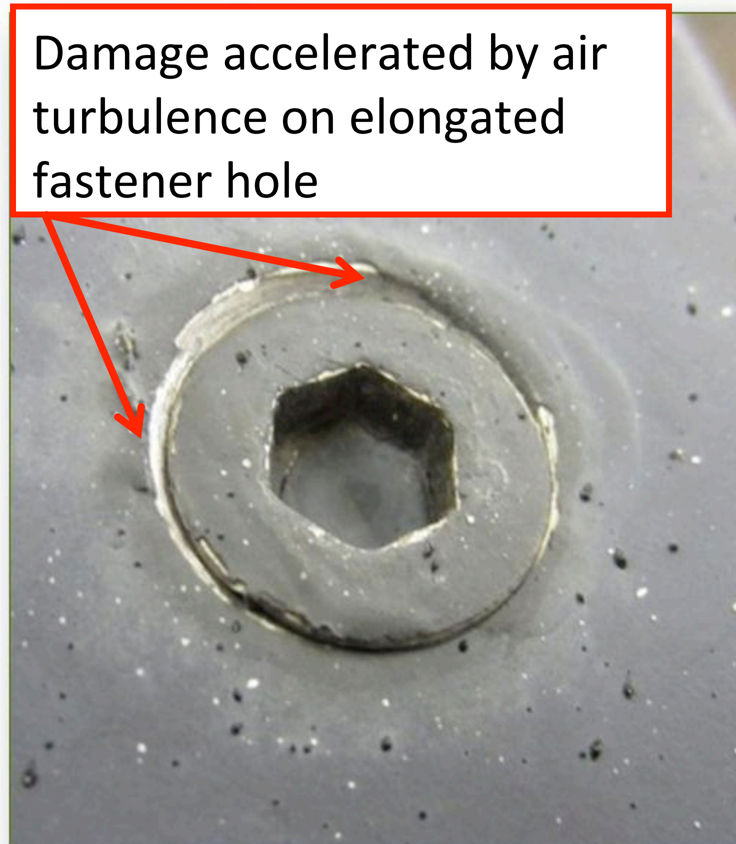


R3S
Repair, Refurbish, and Return to Service

Christian.Widener@SDSMT.edu

Example: Worn Fastener Holes

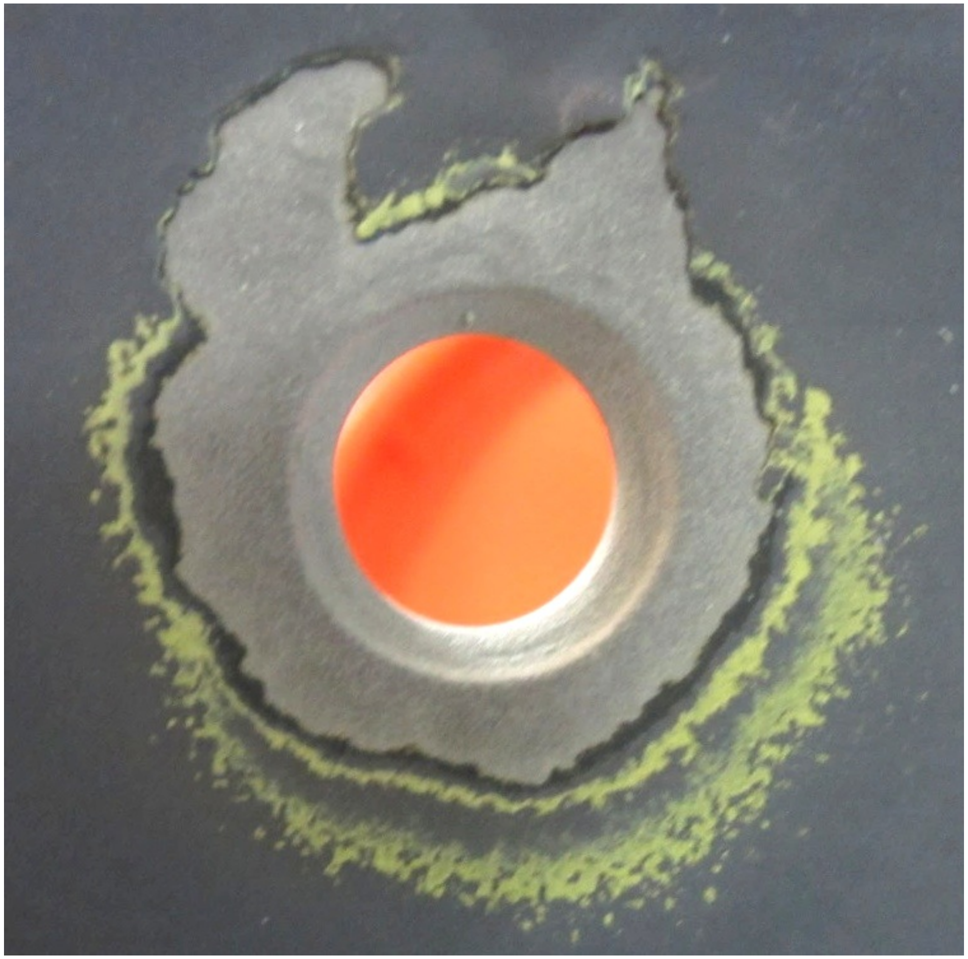




Christian.Widener@SDSMT.edu

Grit Blast

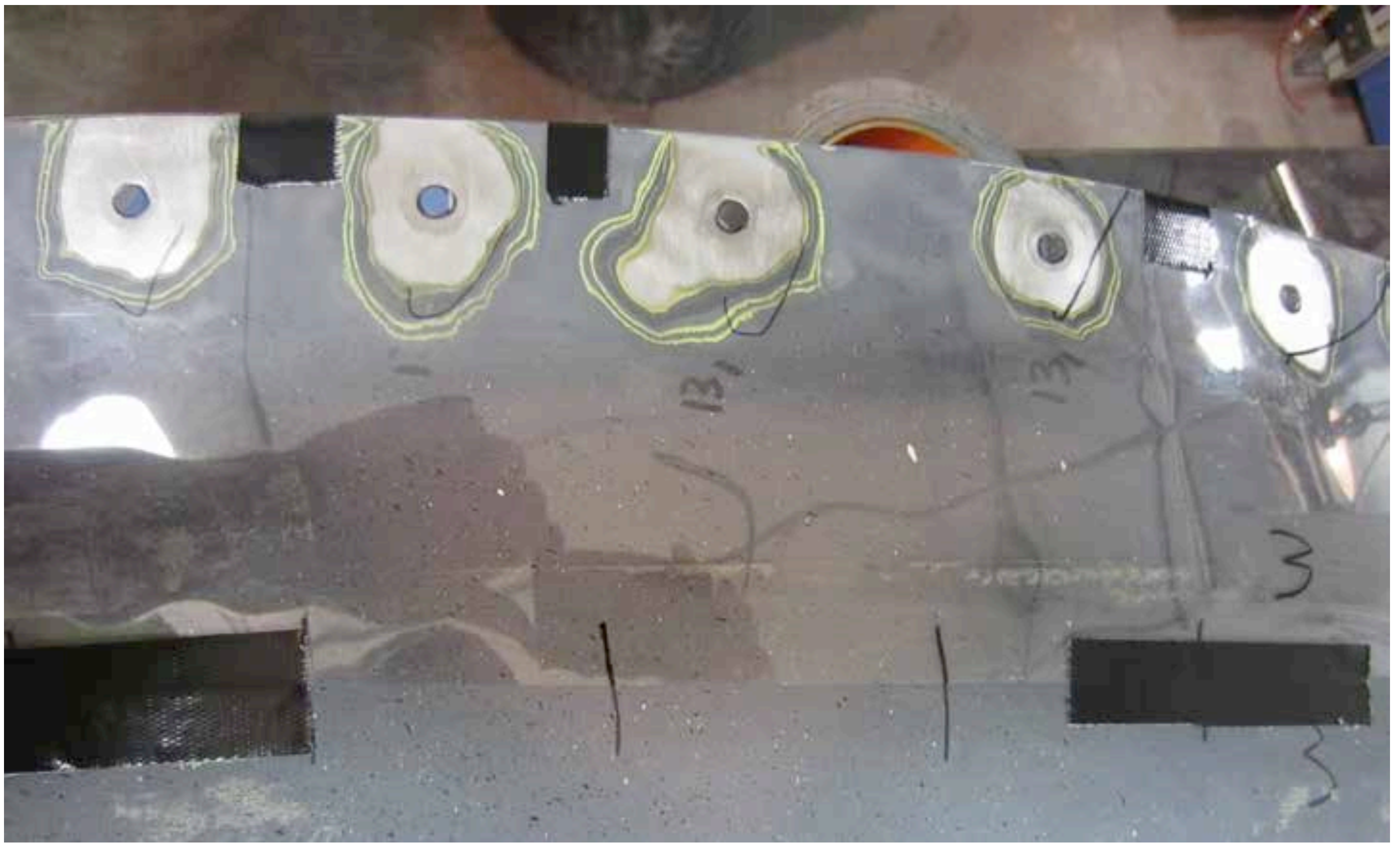
- Each hole was grit blasted prior to cold spray to remove paint from the area and to enhance bonding to the surface.



Christian.Widener@SDSMT.edu

Template

- Templates were created on Mylar from the existing fastener holes prior to performing the cold spray repair.



Repair, Refurbish, and Return to Service

Christian.Widener@SDSMT.edu

Thermocouple Data

- Temperatures on the back side of the panel were monitored by thermocouple and did not exceed 100°C.
- Max. observed transient temp during repair was 153°F, but 137°F shown here was typical (<63°C).

There is no detrimental effect to the 2024 or composite material substrate at these temperatures.

Repair, Refurbish, and Return to Service

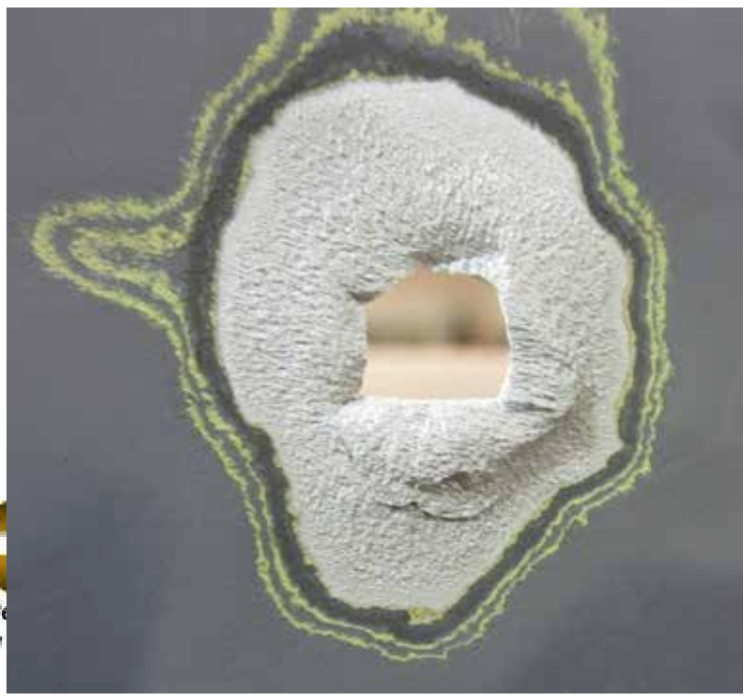
Christian.Widener@SDSMT.edu

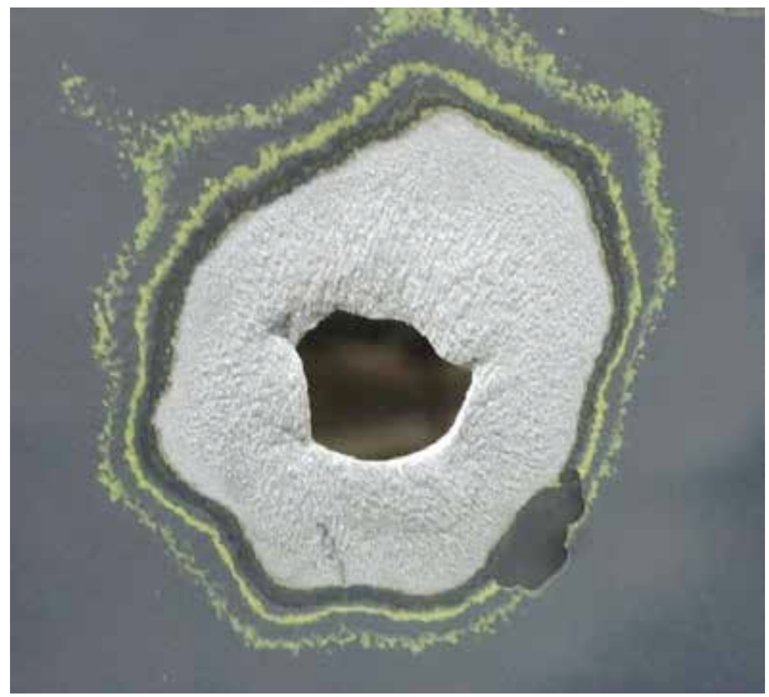
Gen II Prototype CS System

Christian.Widener@SDSMT.edu

Cold Spray

- HP cold spray depositions were added by hand to the surfaces of the worn fastener holes.
- Gen II prototype HP CS system
- 350 psi, 350°C, A0027 Centerline powder –Ultralife^{TM} nozzle

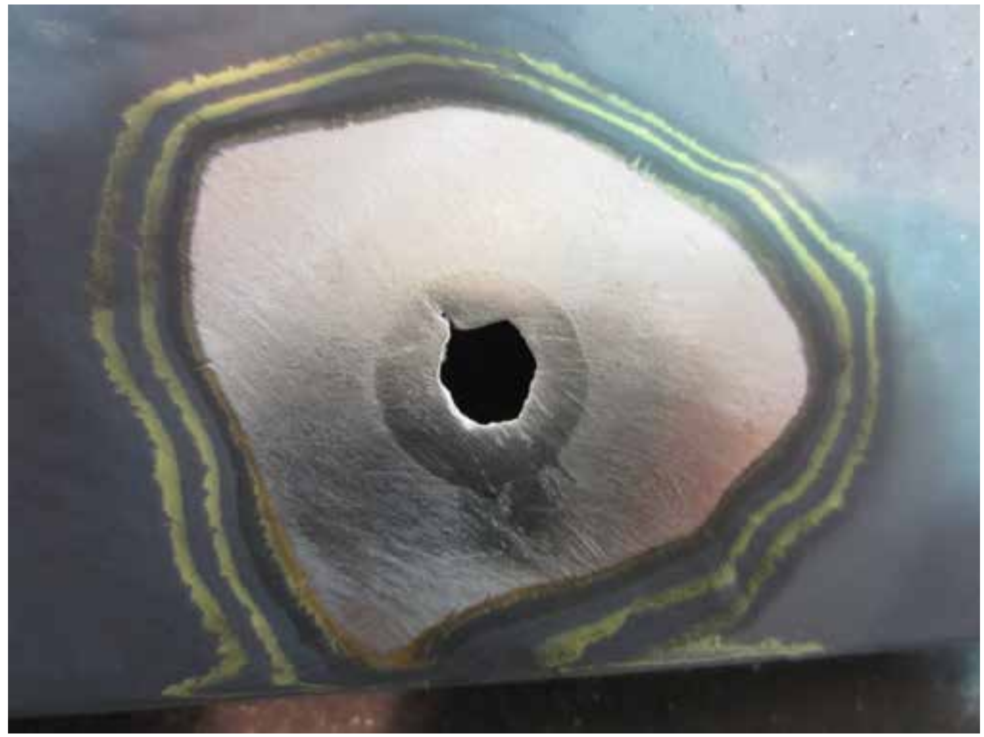




Christian.Widener@SDSMT.edu

Fine Polish

- After grinding, the holes were polished with fine scotch brite discs.



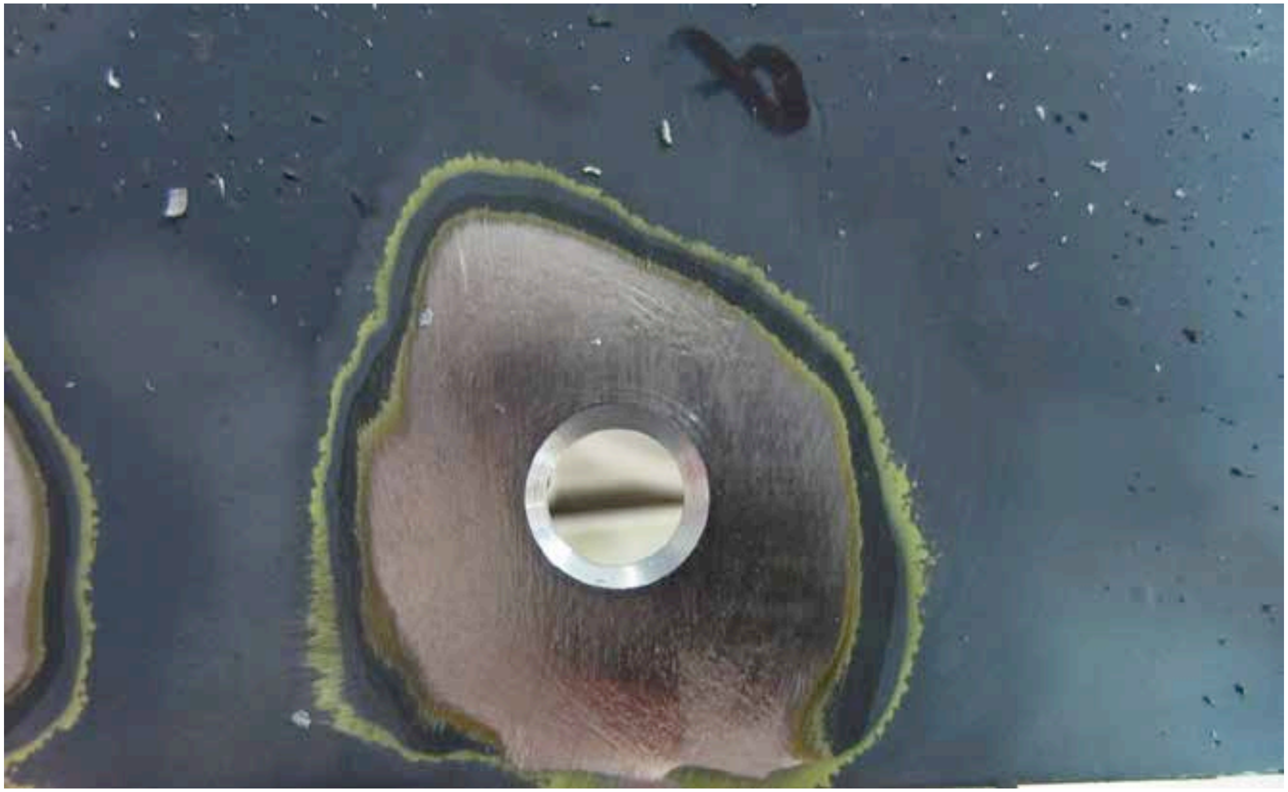
R3S
Repair, Refurbish, and Return to Service

SOUTH DAKOTA SCHOOL OF MINES & TECHNOLOGY

Christian.Widener@SDSMT.edu

Hole after Micro-Stop

- Final machining was performed using a micro-stop tool to cut the proper chamfer for the Tridair fastener.



Repair, Refurbish, and Return to Service

Christian.Widener@SDSMT.edu

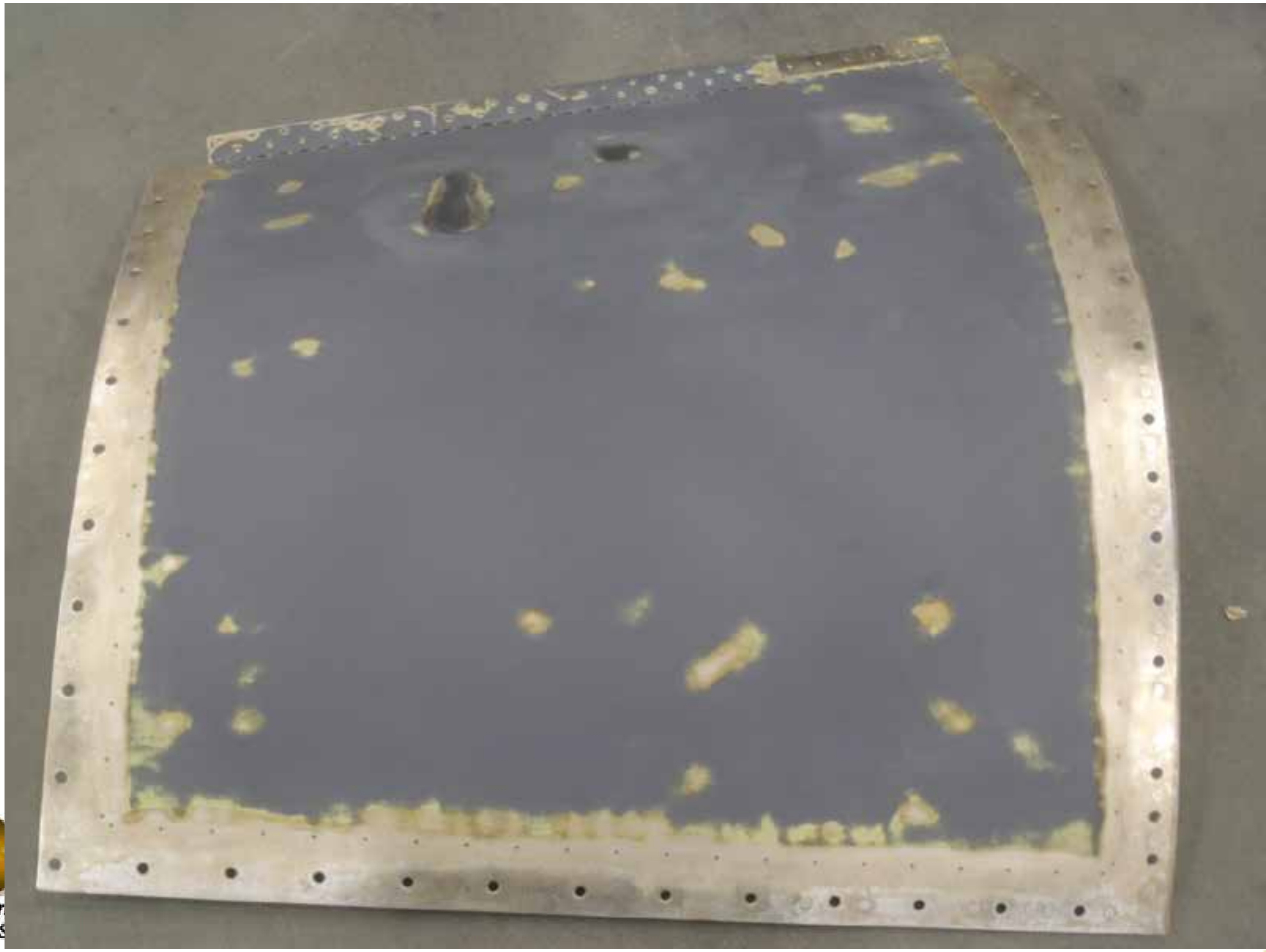
After Micro-Stop

- Final repair before painting.

R3S
Repair, Refurbish, and Return to Service

Christian.Widener@SDSMT.edu

A5083 FEB Door – Paint Prep (Alodined)

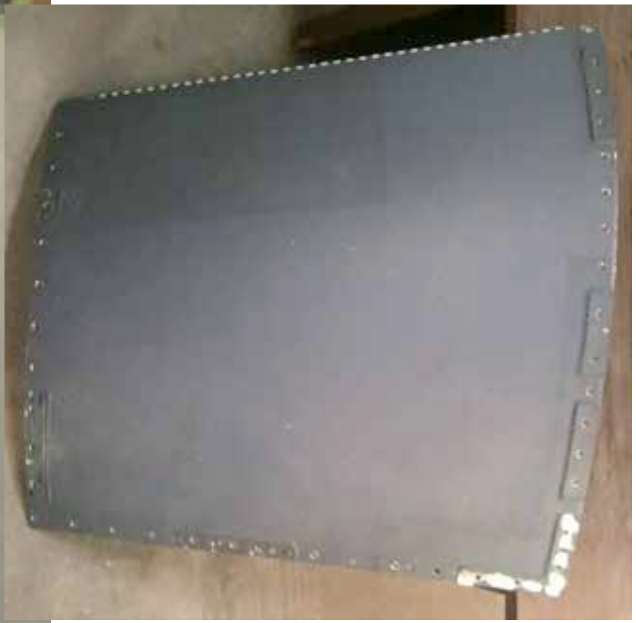


Christian.Widener@SDSMT.edu

A5083 FEB Door – Primed

Christian.Widener@SDSMT.edu

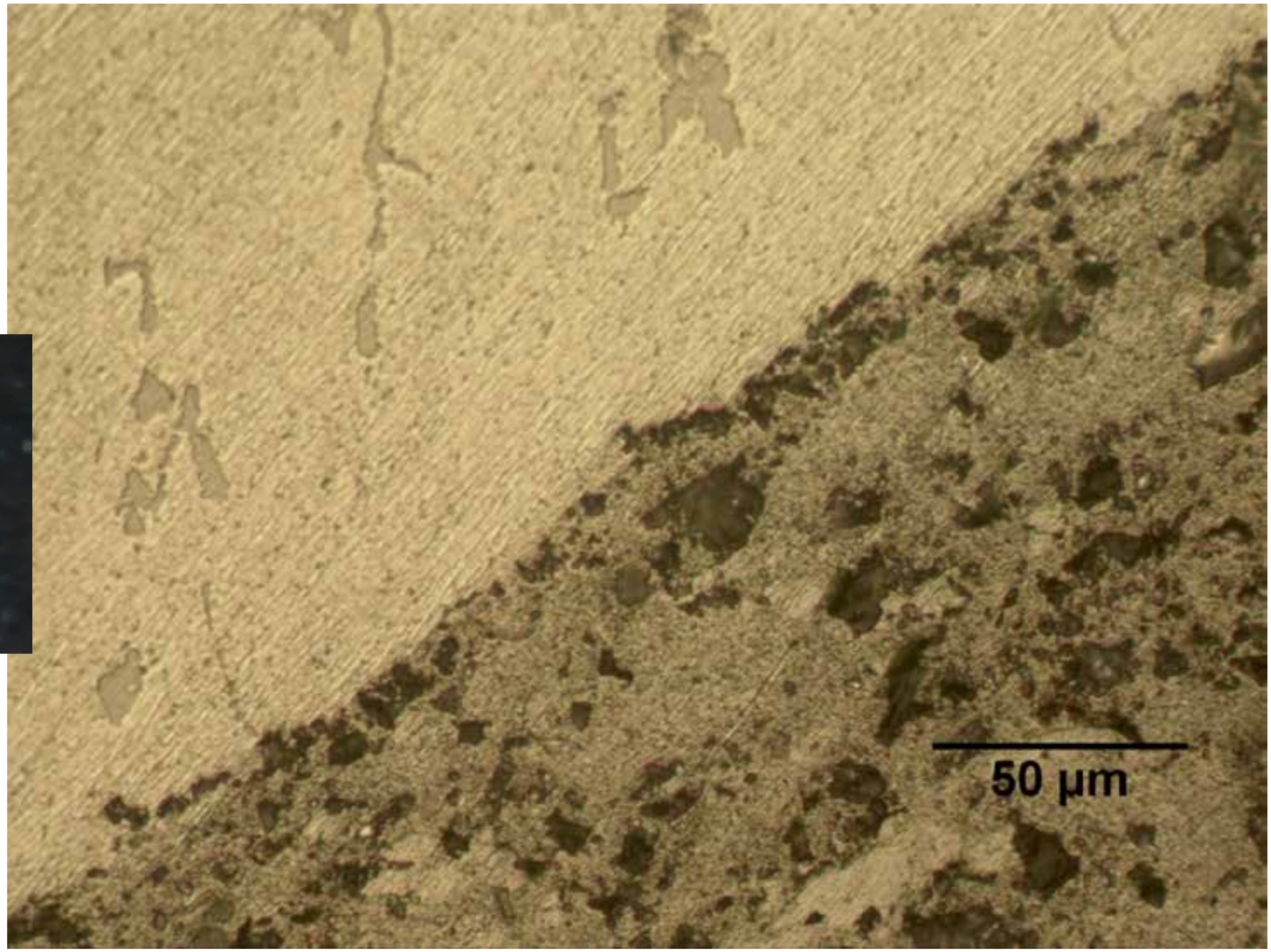
A5083 FEB Door – Top Coat applied



Repair, Refurbish, and Return to Service

Christian.Widener@SDSMT.edu

Cold Spray Interface Macro

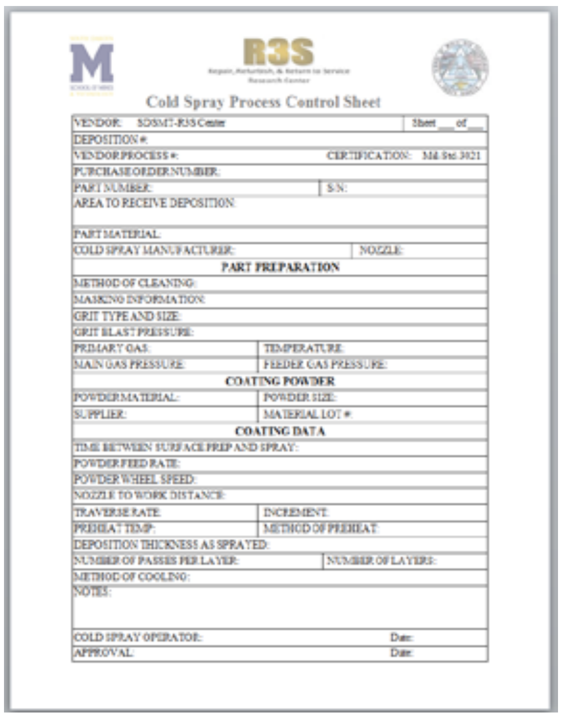


Repair, Refurbish, and Return to Service

Christian.Widener@SDSMT.edu

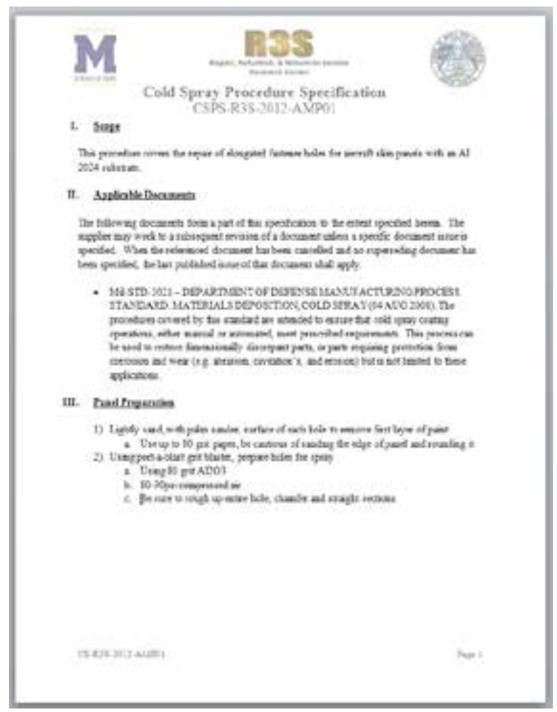
Procedure

- Sprayed at SDSMT using a Gen II System
- A procedure for the repair of the fastener holes using cold spray was prepared by the R3S Center at SDSMT: CSPS-R3S-2012-AMP01.
  - The specification covers the repair of elongated fastener holes in 2024 aluminum sheet for aircraft skins.
  - The repair was documented using a cold spray process control sheet.



Cold Spray Process Control Sheet

VENDOR: SDSMT-R3S Center	Sheet ___ of ___
DEPOSITION #:	
VENDOR PROCESS #:	CERTIFICATION: Mil Std 3021
PURCHASE ORDER NUMBER:	
PART NUMBER:	S/N:
AREA TO RECEIVE DEPOSITION:	
PART MATERIAL:	
COLD SPRAY MANUFACTURER:	NOZZLE:
PART PREPARATION	
METHOD OF CLEANING:	
MASKING INFORMATION:	
GRIT TYPE AND SIZE:	
GRIT BLAST PRESSURE:	
PRIMARY GAS:	TEMPERATURE:
MAIN GAS PRESSURE:	FEEDER GAS PRESSURE:
COATING POWDER	
POWDER MATERIAL:	POWDER SIZE:
SUPPLIER:	MATERIAL LOT #:
COATING DATA	
TIME BETWEEN SURFACE PREP AND SPRAY:	
POWDER FEED RATE:	
POWDER WHEEL SPEED:	
NOZZLE TO WORK DISTANCE:	
TRAVERSE RATE:	INCREMENT:
PREHEAT TEMP:	METHOD OF PREHEAT:
DEPOSITION THICKNESS AS SPRAYED:	
NUMBER OF PASSES PER LAYER:	NUMBER OF LAYERS:
METHOD OF COOLING:	
NOTES:	
COLD SPRAY OPERATOR:	Date:
APPROVAL:	Date:



Cold Spray Procedure Specification
CSPS-R3S-2012-AMP01

I. Scope

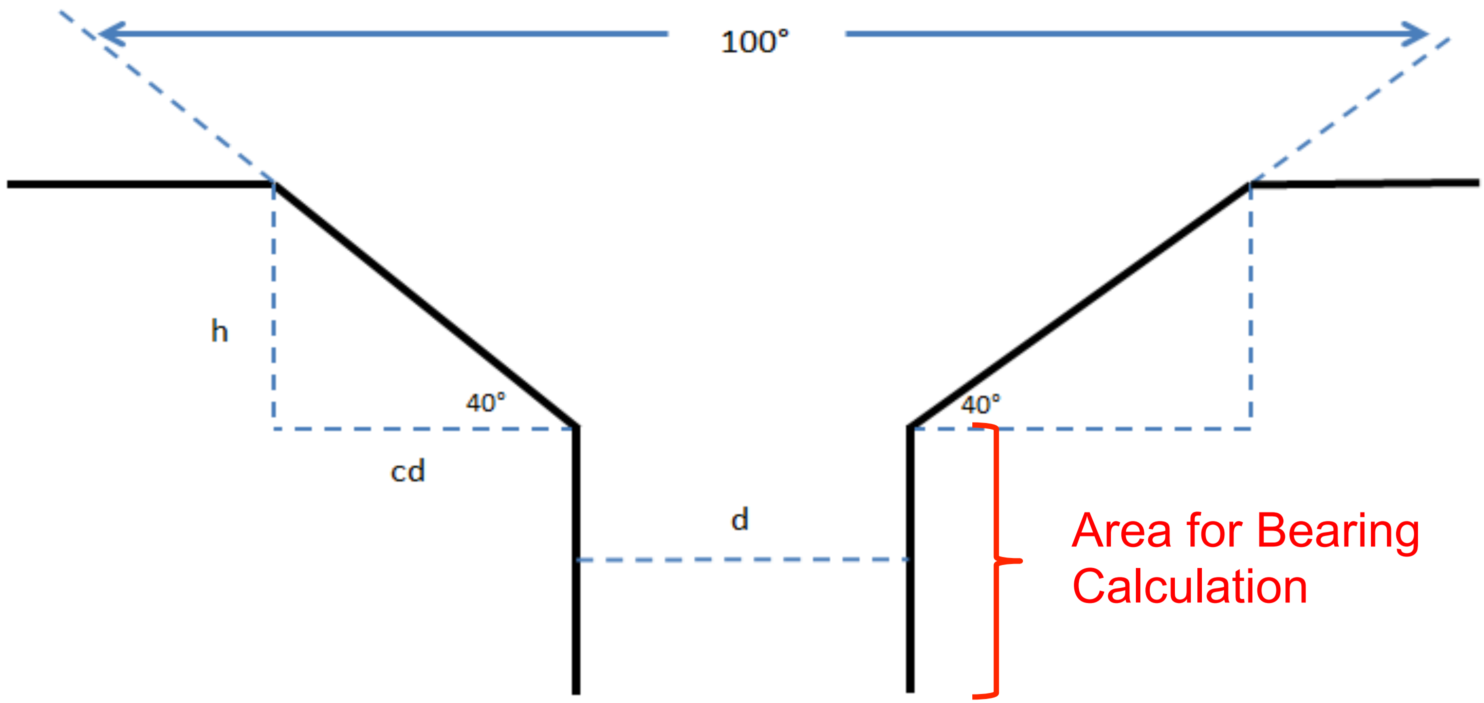
This procedure covers the repair of elongated fastener holes for aircraft skin panels with an Al 2024 substrate.

II. Applicable Documents

III. Panel Preparation

Christian.Widener@SDSMT.edu

Counter-Sink Schematic



Christian.Widener@SDSMT.edu

Bearing Load Calculation

- Based on Mil-HDBK-5H guidelines, section 1.4.7, calculated bearing load depends on straight section thickness.
- Measured panel thickness of 0.147-in. leads to a max load of 3369 lbs.

$$P = Fbry * (t - h) * d \qquad h = \tan(40°) * (cd - d/2)$$

t=0.095-in. bearing surface

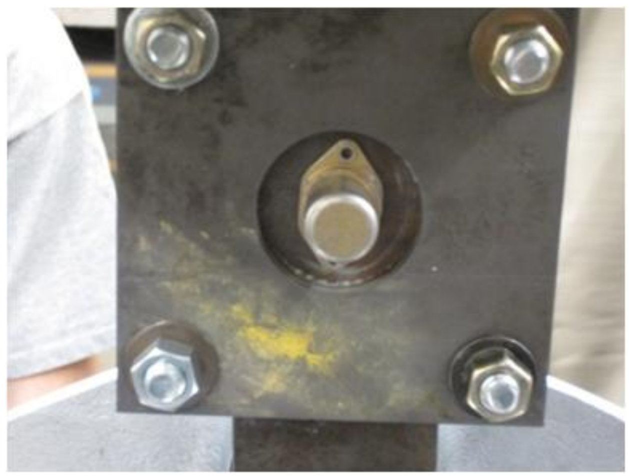
Edge Distance	e	1.25	in
Hole Diameter	D	0.375	in
e/D	3.333333		
Bearing Yield Stress	Fbry	95000	psi
Hole Diameter	d	0.375	in
Thickness	t	0.147	in
Countersink Depth	h	0.052	in
Load	P	3369	lbs

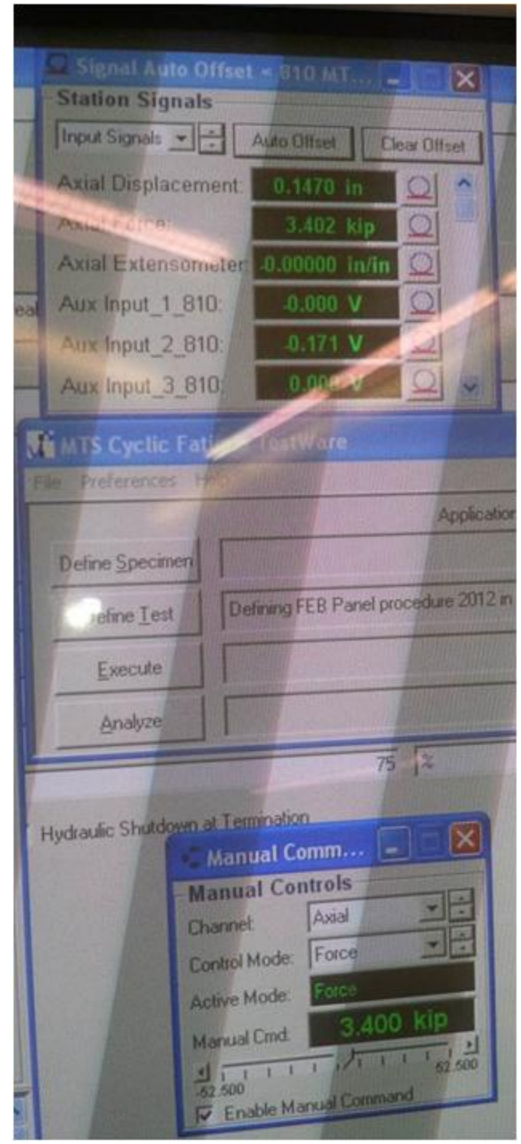
R3S Repair, Refurbish, and Return to Service

Christian.Widener@SDSMT.edu

Testing Procedure

- Guided lap shear
- Fastener torque applied = 40 in-lbs
- Carried full Mil-HDBK fastener bearing yield load of 3400lbs.
- Tested up to failure at 5600 lbs – **no delamination at failure**





Repair, Refurbish, and Return to Service

Christian.Widener@SDSMT.edu

Mechanical Testing

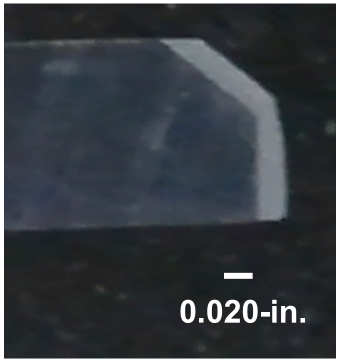
Cold Spray Adhesion

- Three lug shear testing
- >5000 psi avg. interface strength (Avg. 5681 psi ± 729)

Christian.Widener@SDSMT.edu

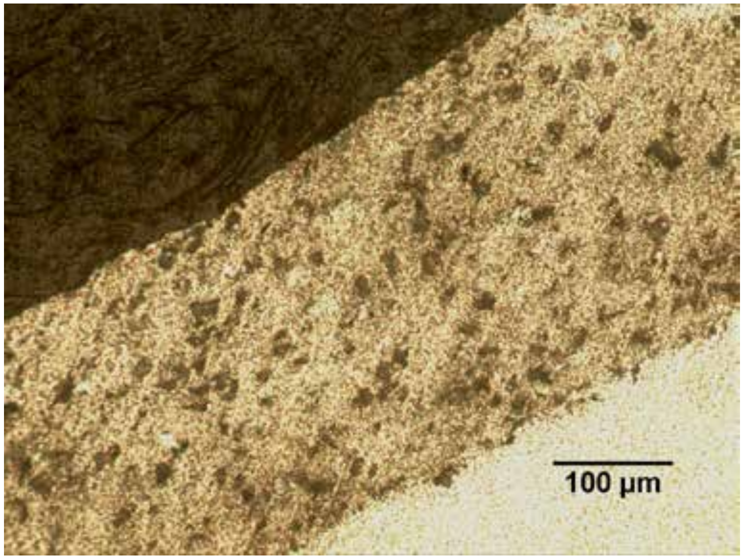
Testing Results

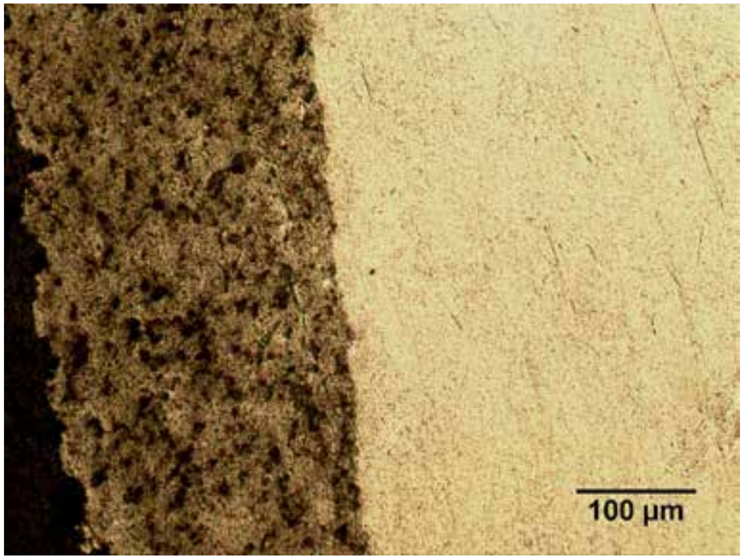
No evidence of cold spray material failure observed up to full bearing yield.

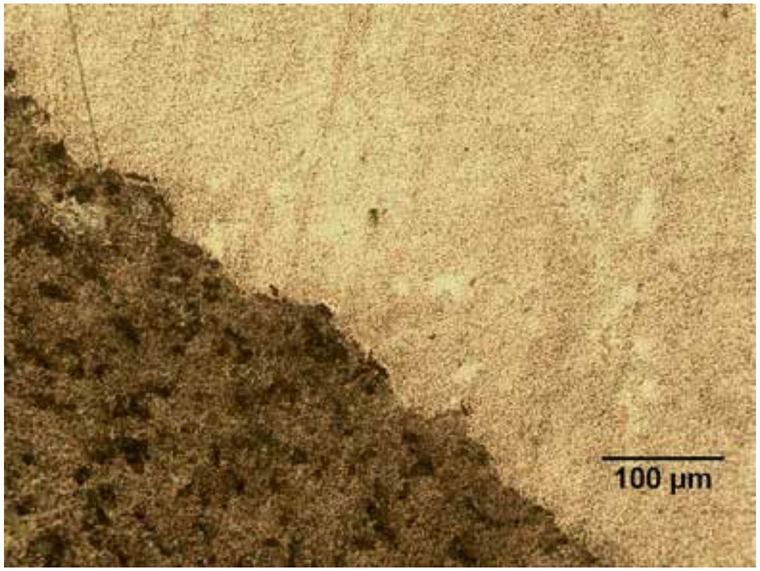


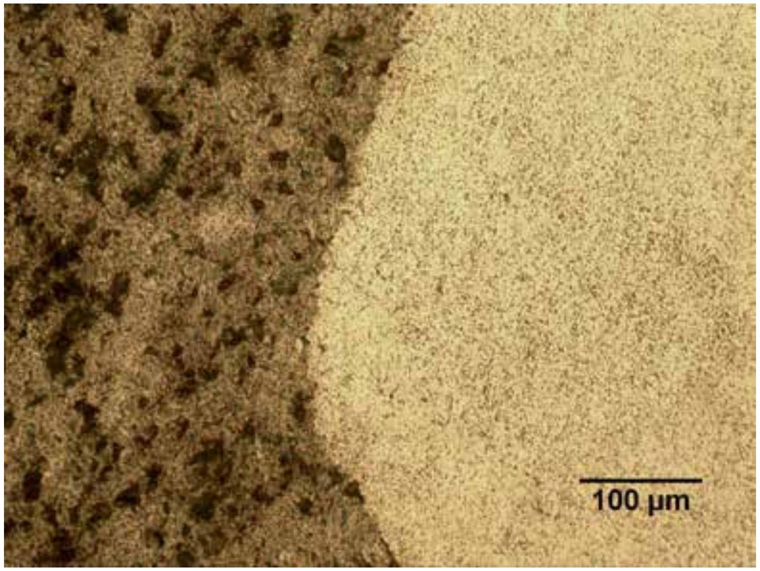
Christian.Widener@SDSMT.edu

Tested Coupon Micrographs







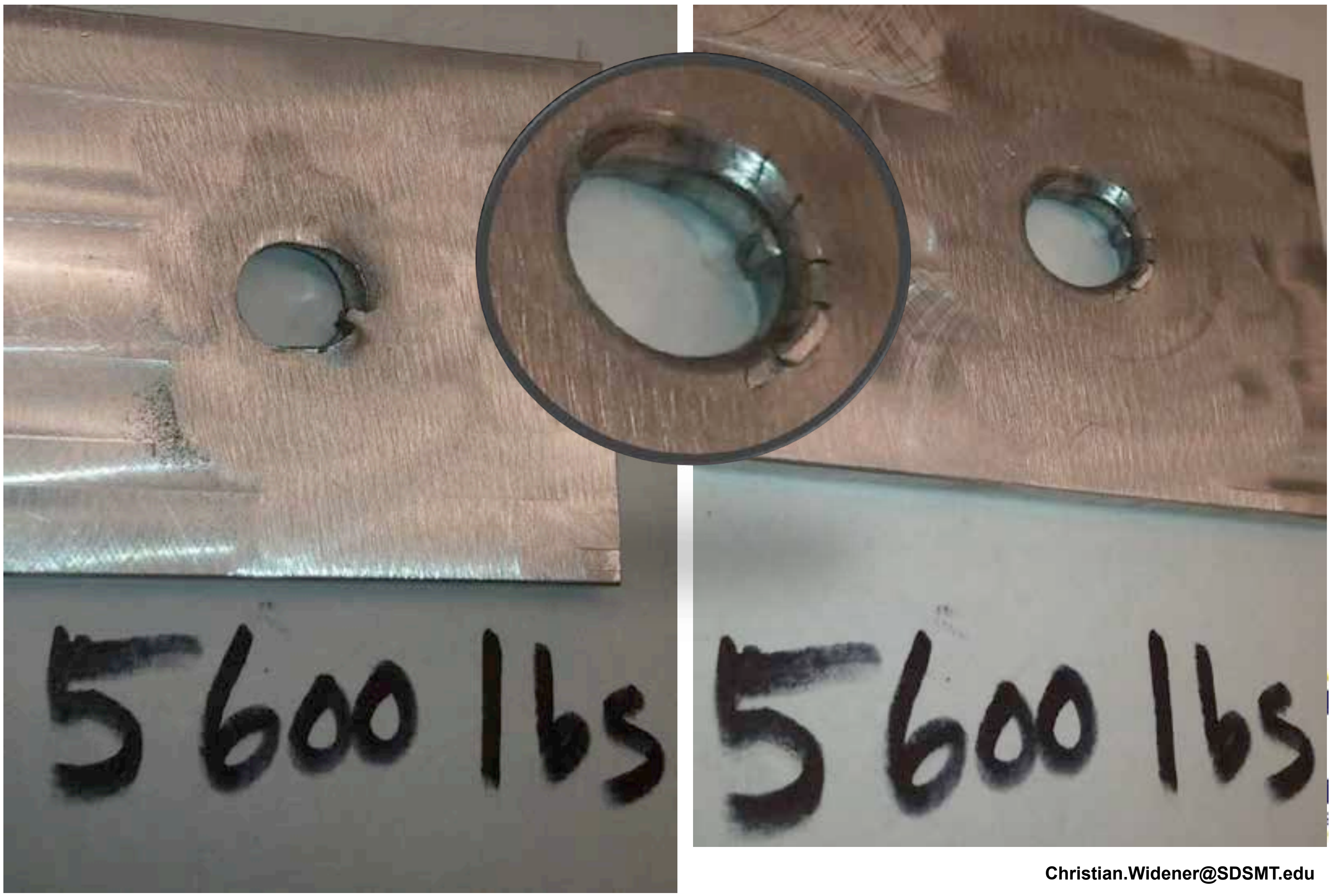


Repair, Refurbish, and Return to Service

Christian.Widener@SDSMT.edu

Failure Load Testing

- Even tested up to failure at 5600lbs, the cold spray material did not separate from the coupon.



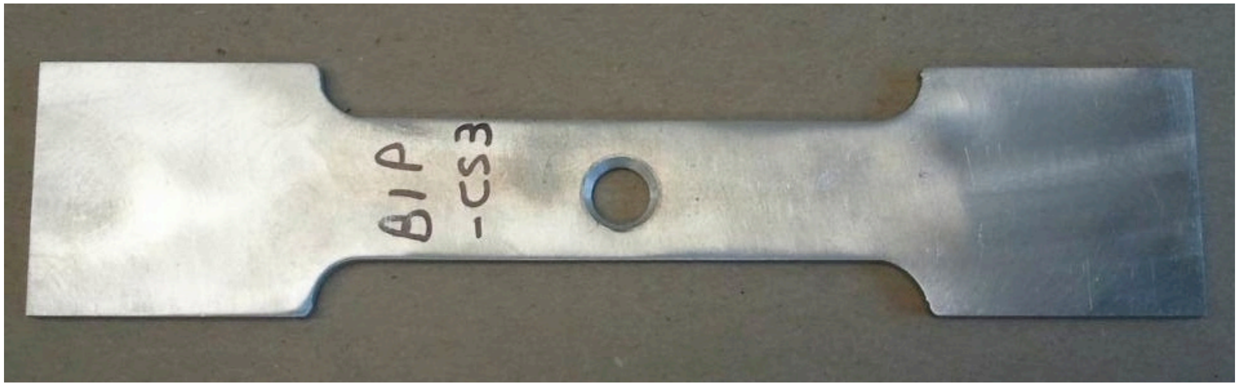
Repair, Refurbish, and Return to Service

Christian.Widener@SDSMT.edu

Mechanical Testing

Fatigue Testing

- Open hole fatigue testing
- Coupons prepared per CSPS-R3S-2012-AMP01
- Testing performed per ASTM E466
- R=0.1
- At 15 ksi tensile stress (typical upper end for aircraft skin design loads) coupons lasted approx. 500,000 cycles.



R3S
Repair, Refurbish, and Return to Service

Christian.Widener@SDSMT.edu

Conclusions

- Panels can be restored to their full form, fit, and function.
- Cold Sprayed coupons **met or exceed the required bearing loads** for the parent material and fastener type for this application.
  - Even when tested to failure (greater than 1.5 x bearing yield) the cold spray material did not separate from the panel.
- The repair is expected to have an acceptable lifetime in service, and represents minimal risk of failing in service.
- The coating could even be reapplied if needed, since the process does not overage the substrate material.
- ***The repair is currently flying on a B1 under an ETAR (since August 2012).***

Repair, Refurbish, and Return to Service

Christian.Widener@SDSMT.edu

Future Efforts

- The process is now being licensed by MOOG, and has potential application on other DoD and commercial aircraft
- A broad collaborative effort is also being initiated with the support of Tinker AFB to do a much larger qualification program to consider making it a part of the approved repair procedures for the B1.
  - Full qualification testing protocol, including spray parameters & powders
  - Identify opportunities on other aircraft
- *Continue development of VRC-Gen III HP Hybrid Cold Spray System…*

R3S Repair, Refurbish, and Return to Service

Christian.Widener@SDSMT.edu