Repair and Refurbishment Lessons Learned Using Cold Spray

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OUTLINE

- Why Repair? *(can't you just buy a new one?)*
- Risk vs. Return *(picking the best low hanging fruit)*
- Evaluating Risk *(and understanding current risks)*
- The Repair Process *(from coupons to real parts)*
- Examples
- More Lessons Learned
- Summary

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Why repair?

LEAD TIMES

1. Lead times for new replacement parts are unacceptable

Cost Savings

2. Sustainment budgets are not enough to meet growing costs

No Availability

3. Lack of availability of replacement parts

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Cost of Down Time

- Common weapon system values: $14M - $300M
- Lost value can be estimated using a commercial rule of thumb at 1% of system price per month…

Lost Value from
Weapon System Down Time:
$140,000 to $3,000,000 <u>per month</u>

- Due to a lack of repair options or replacement parts which cause a lack of weapon system availability.

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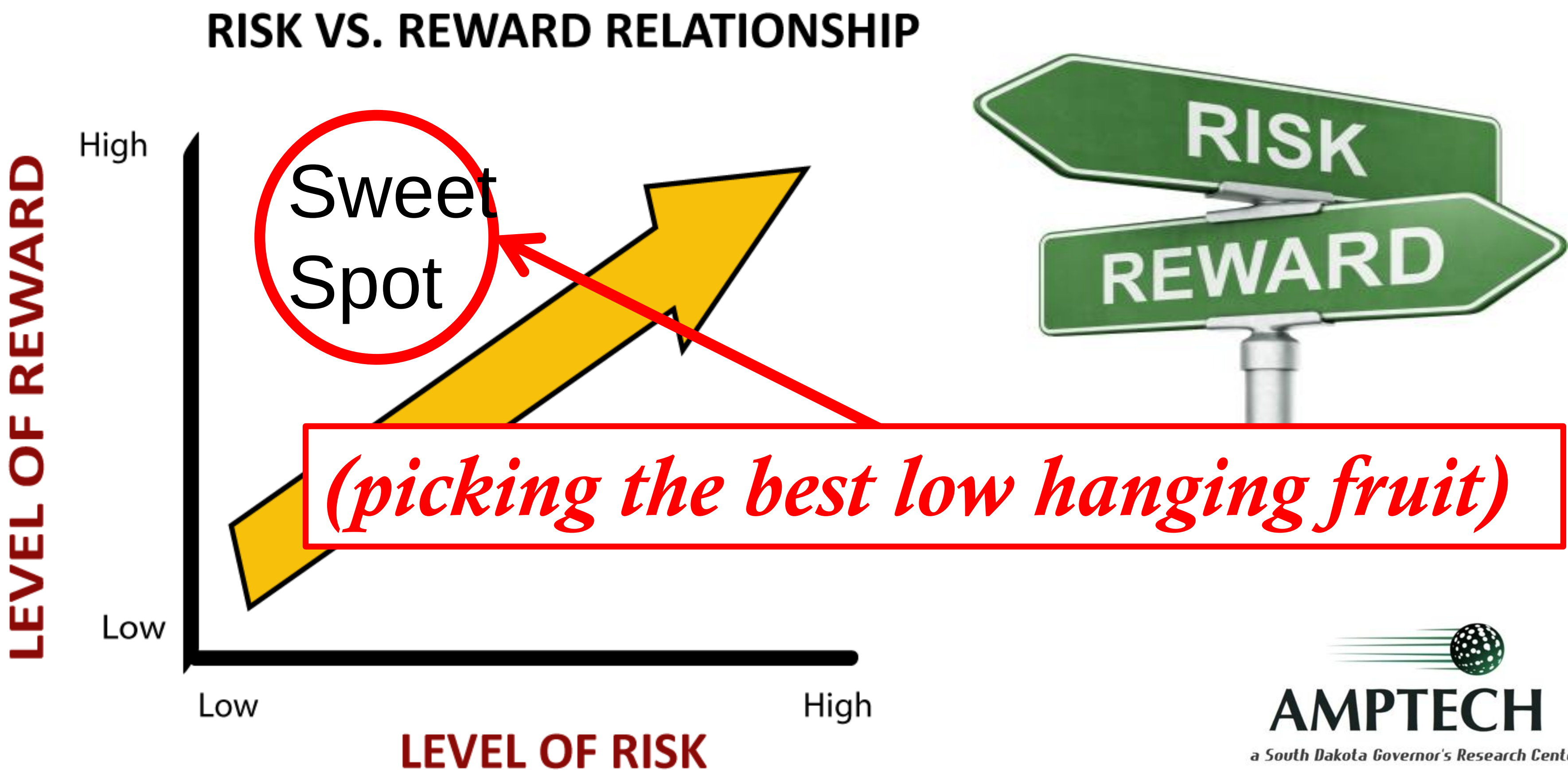
Risk vs. Return

Taking Risks is NOT Wrong…It is Necessary and Vital



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Current Risk vs. Repair Risk

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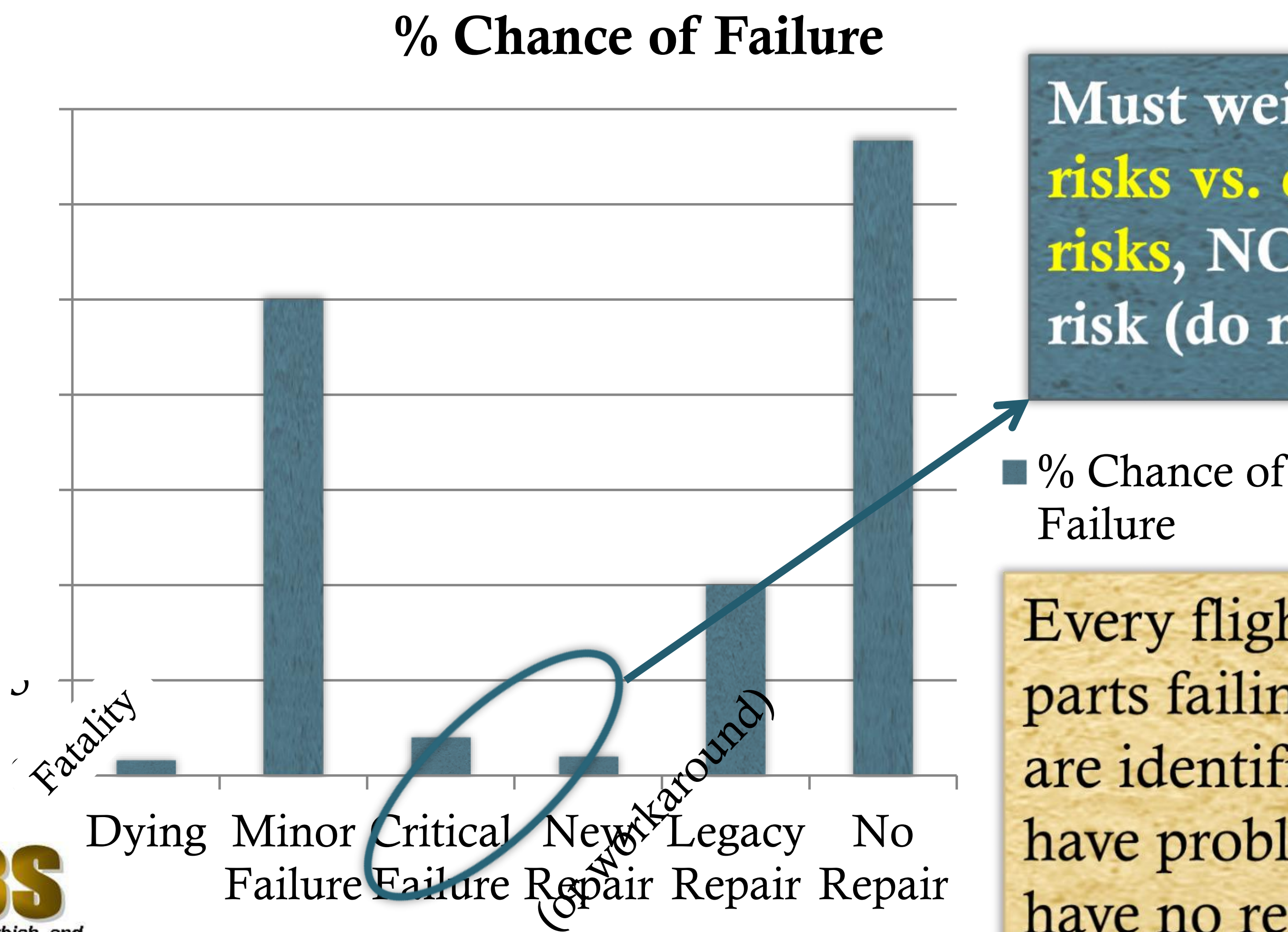

Must weigh repair risks vs. current risks, NOT zero risk (do no harm).

Every flight has parts failing or that are identified to have problems but have no replacement

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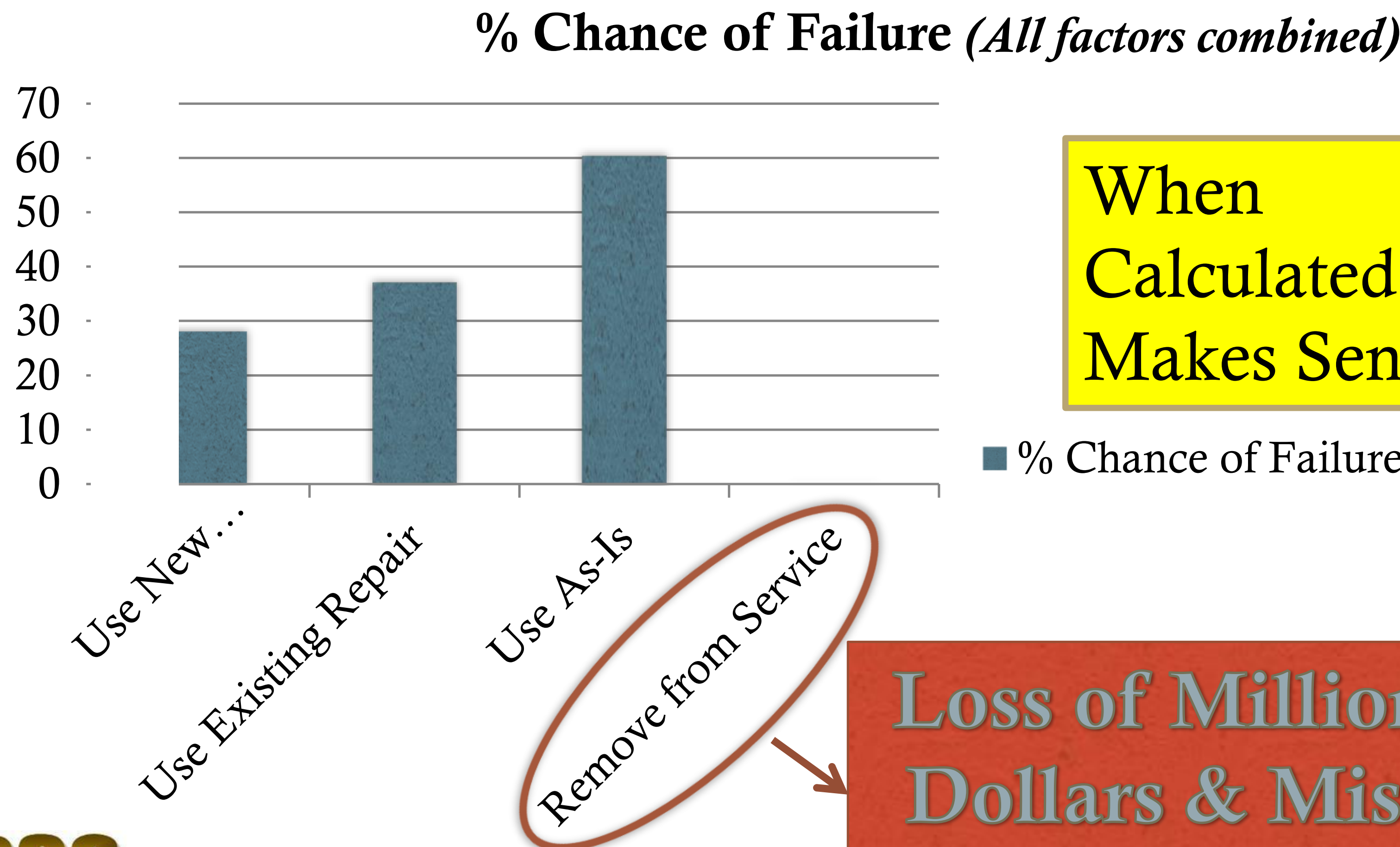
Combined Total Risk



When Calculated Risk Makes Sense…

Loss of Millions of Dollars & Mission Capability

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The Risk of Doing Nothing

- Weapon system sustainment efforts need new technology…how do we deliver it **<u>in time</u>**?

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Goal: Warfighter Needs Total Solution Delivery in 180 days or less…

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The Repair Process

War-fighter Need →

Identify Potential Technology Solutions →

Develop Solution →

Gather Stakeholders →

Define **<u>clear and realistic</u>** minimum qualification requirements →

Develop a staged implementation strategy with fielded repairs →

Refine process based on lessons learned →

Release Repair Standard

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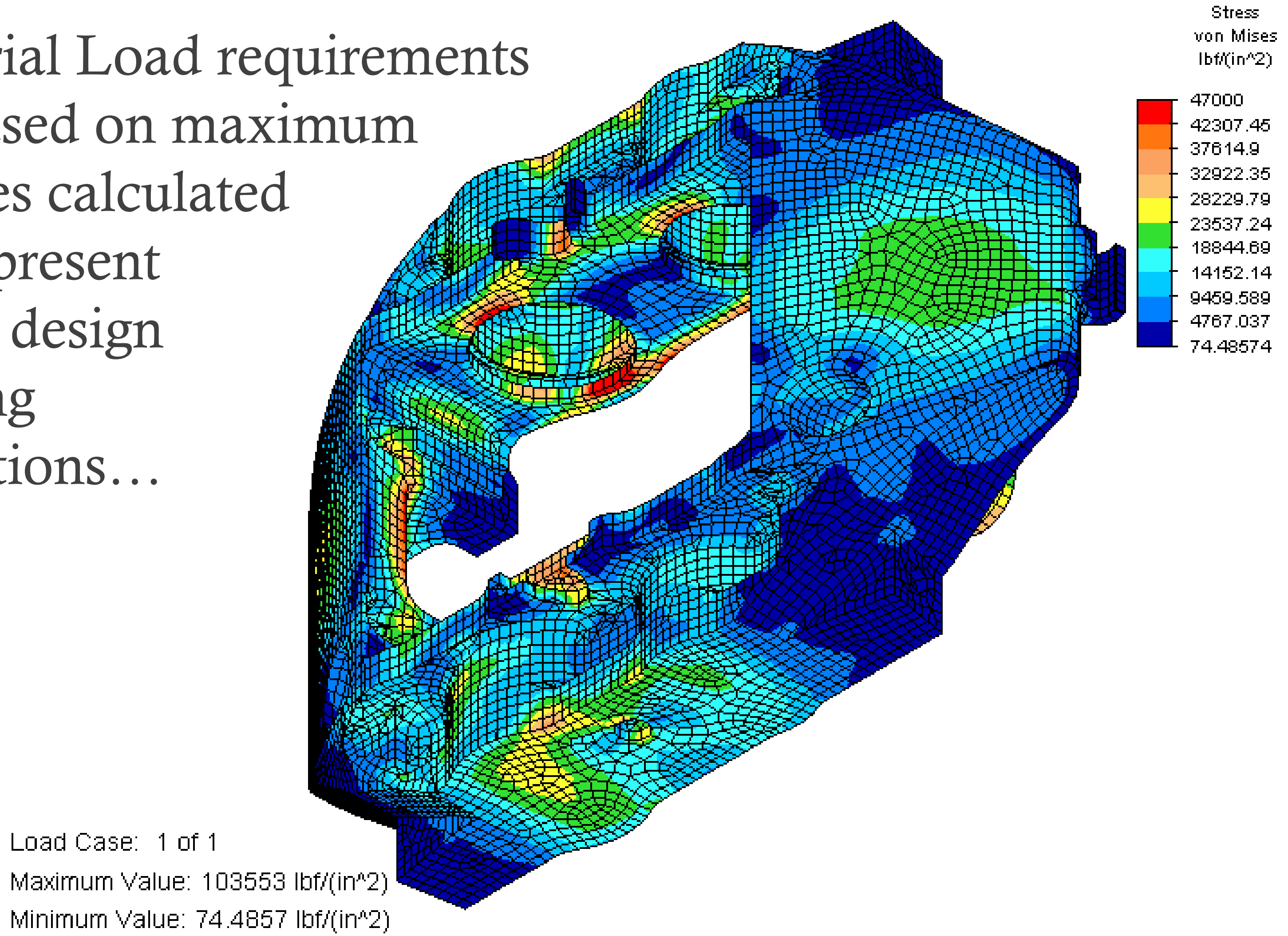
Realistic Requirements

- Requirements must be based on material properties AND service requirements.
- CANNOT default to simple virgin material standards.
  1. Used parts are no longer comprised of virgin material
  2. Used parts no longer possess full material life expectancy
  3. Real parts have variable loading levels across the part, usually well below design stresses…

Material Stress Requirements

- Material Load requirements are based on maximum stresses calculated to be present under design loading conditions…



Strength Requirements

Material Static Strength Allowable

Material Fatigue Strength Allowable

Fatigue Crack Growth Limits

Actual Part Stresses

Repair Material Static Strength

Does this necessarily prevent the opportunity for repair?

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Repair Application Example

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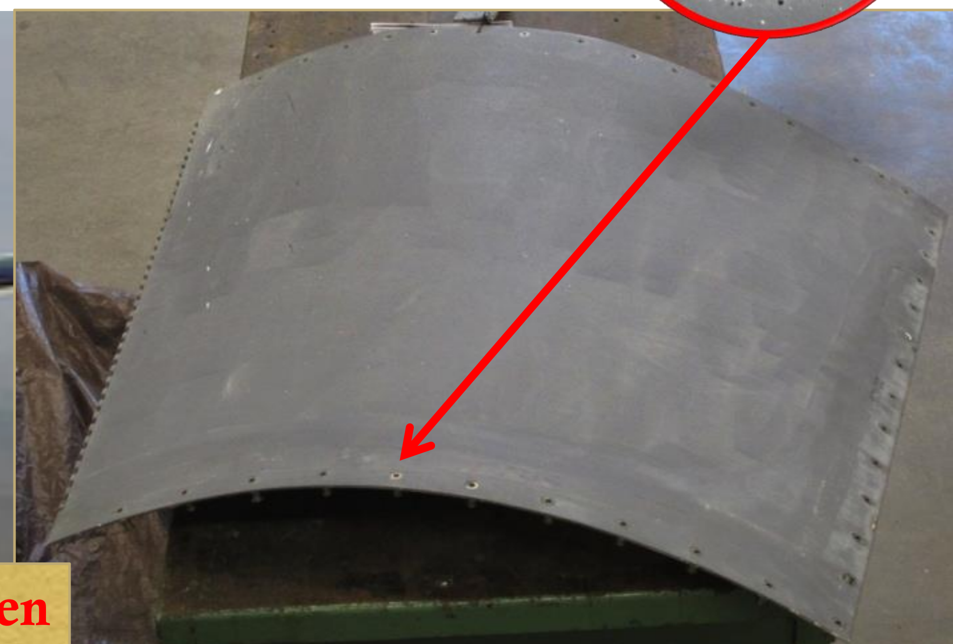
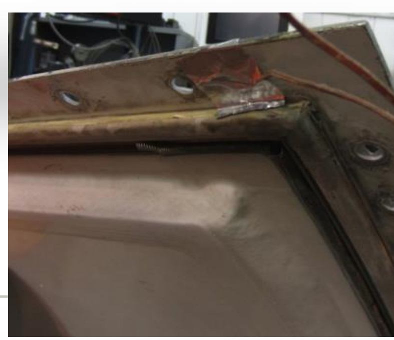
- B1 Bomber Skin Panel Repair
  - Wear at fastener holes
  - Replacement Cost >$200K each (Fleet liability: $50M)
  - Access panel not designed to be load carrying



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

Panel Selected for Refurbishment

- Approved Legacy Repair
  - External Doubler Repair



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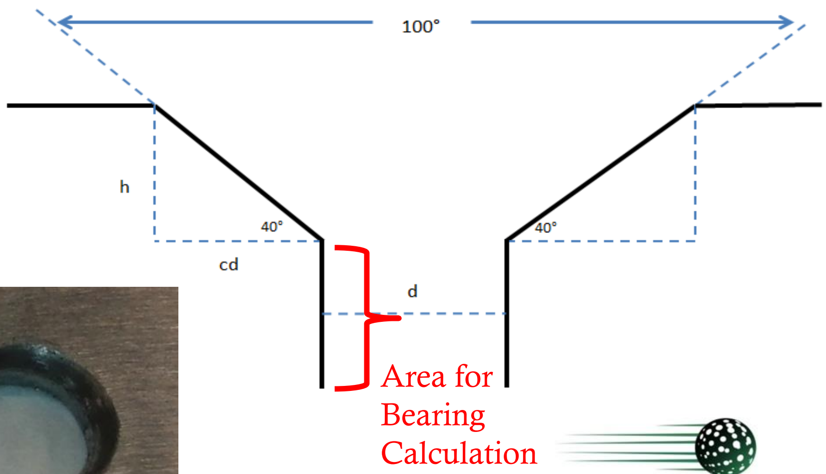
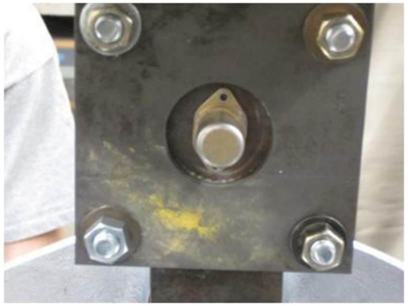
Risk Assessment on FEB

- Why is the FEB low risk?
  1. Since it is an access panel, it is not designed to be load carrying. Loss of the panel in flight would not be catastrophic.
  2. Only a small amount of cold spray (less than 0.030 in. thick and 0.50 in. in diameter) is being installed. Failed material cannot represent a significant FOD risk.
  3. The material being sprayed is physically captured by the head of the fastener and held in place in compression. Failed material cannot become a FOD risk.
  4. The panels are inspected every flight as part of a normal inspection protocol. Any degradation of the coating that could occur would be easily identified during normal operational checks.

Mechanical Testing

- Realistic requirements developed with Tinker AFB engineers
- Fatigue
  - 500K Cycles At 15 ksi
- Three lug shear testing
  - >5000 psi avg. adhesive shear strength
- Static Guided lap shear
  - Carried full Mil-HDBK fastener bearing yield load of 3400lbs.
  - Tested up to failure at 5600 lbs – **no delamination at failure**





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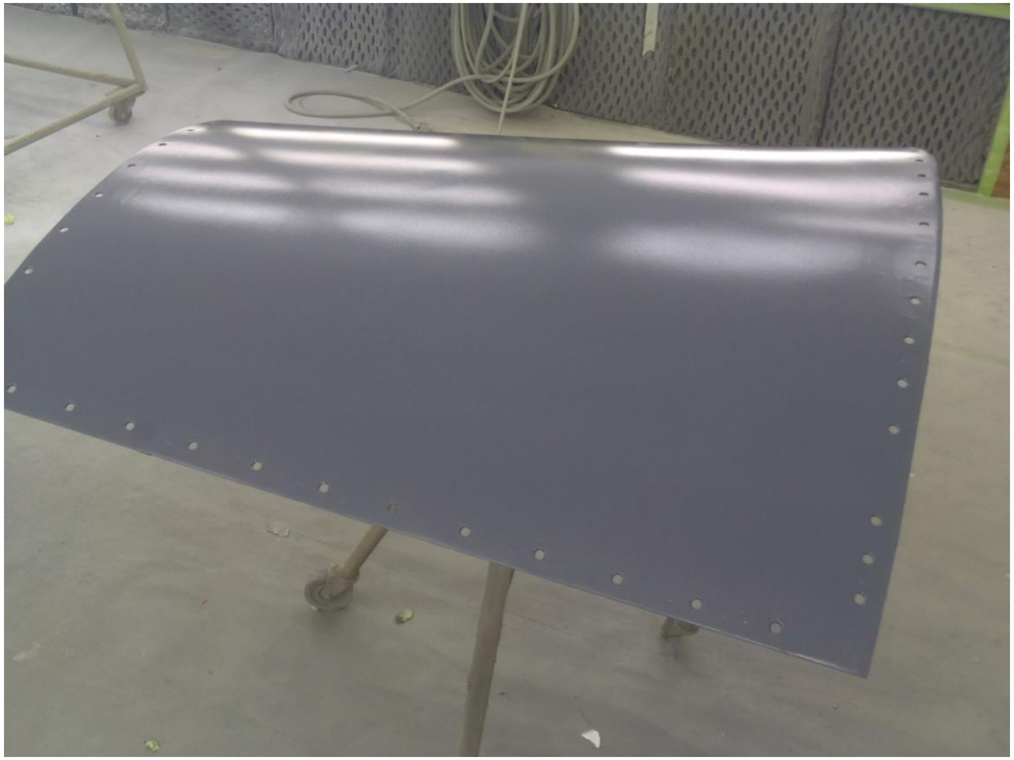
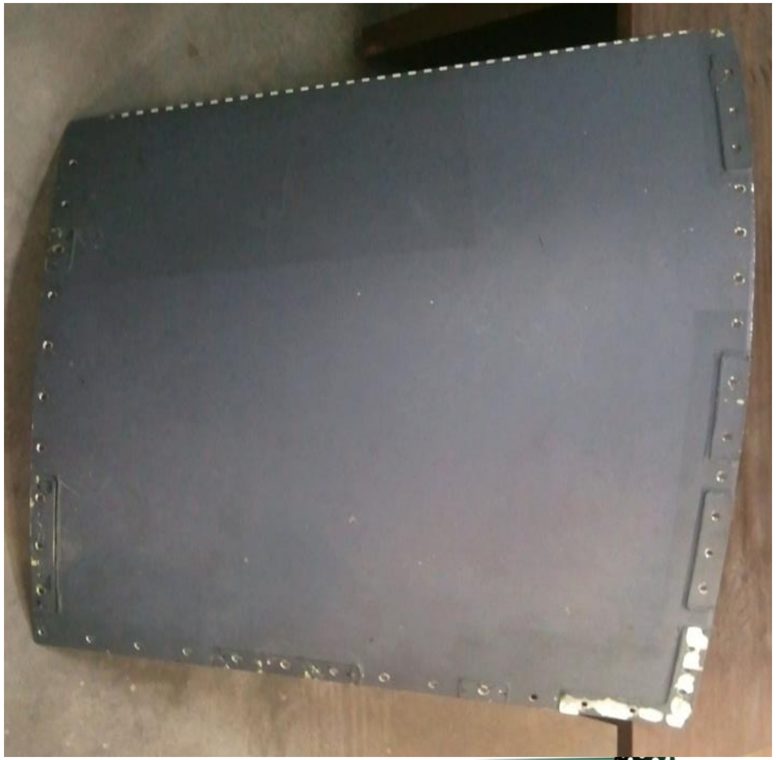
Fully Restored Panel vs. Legacy Repair Options





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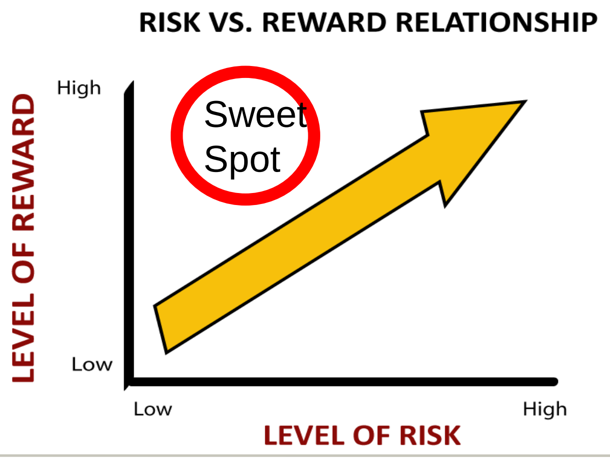
Panel Repair Summary

- ***The repair is currently flying on a B1 under an ETAR (since August 2012)***
- Panels can be restored to their full form, fit, and function
- No sign of degradation or repair failure to date.
- **Total development (with Tinker AFB support): 250 days**
- Low risk and High return



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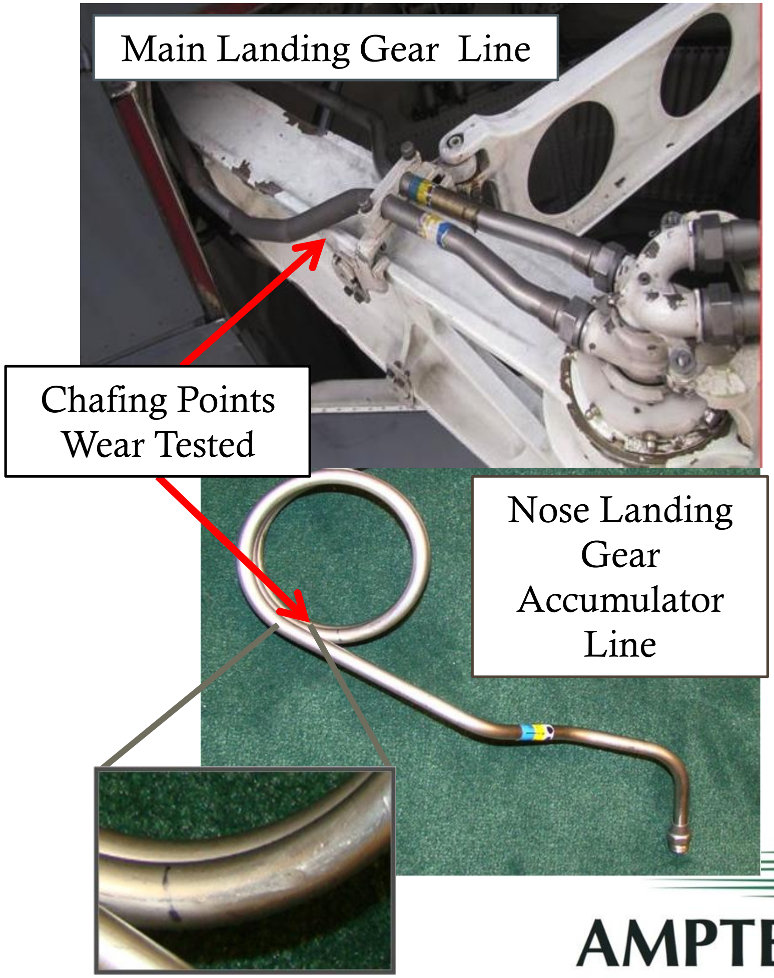
Other Repair Examples

#1 Maintenance Manhour Driver on B-1

- B1 Hydraulic Lines
  - Chafing Prevention
  - CpTi on Ti-3-2.5
  - Flying since 2009…
- Lessons Learned
  - Hand spraying needed because of complexity and variability of tubing bends



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Hydro Tube Qualification

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- What testing should be required to approve a chafe prevention method that is currently being serviced by plastic tape to poor effect?
- High cycle fatigue – 10^7 cycles?
- Bend testing
- Impact testing
- Cryogenic testing
- Stress Corrosion Cracking, etc.

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Hydro Tube Validation

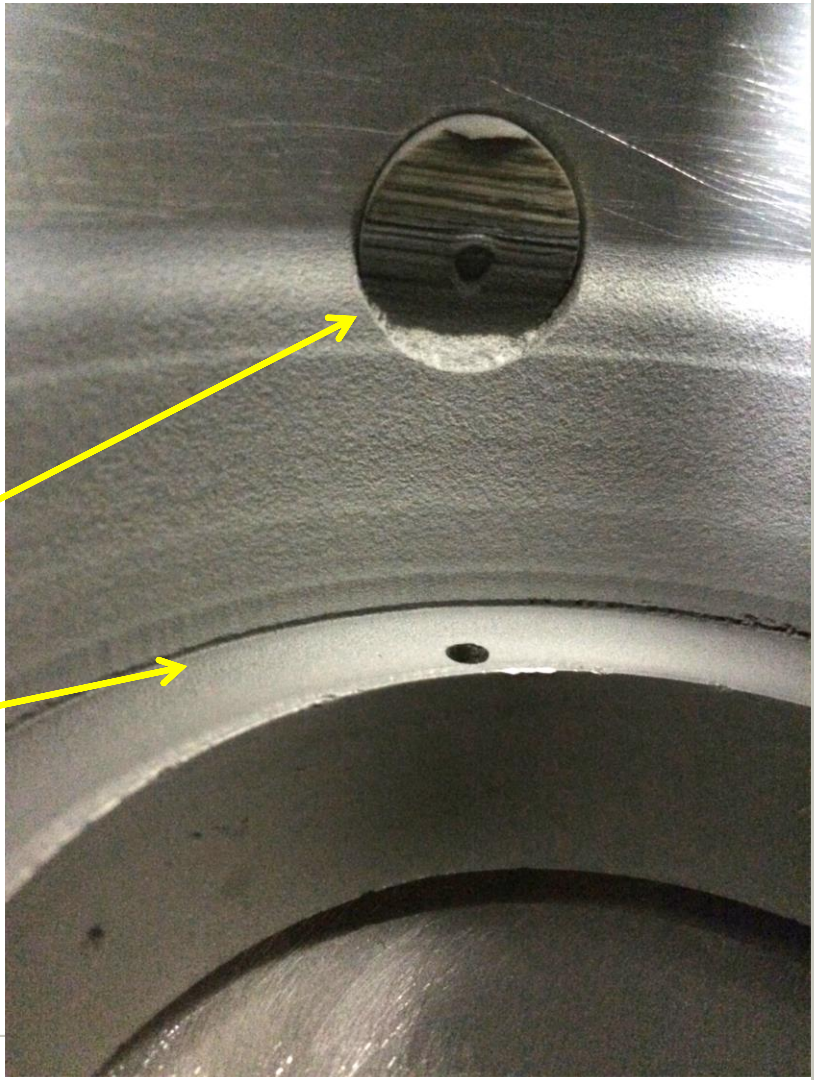
- What do we compare to?
- Pristine perfect tubing?
- Or, tubing with simulated chafing to maximum acceptable limit and/or with the only approved repair to date: swaged connections….
- Comparisons must be between the worst allowable existing approved condition and the best available repair option with cold spray (which may include strength benefits from overbuilding - think fillet weld)

Hand-held High Pressure Cold Spray

- VRC Gen III Cold Spray System
  - 1000 psi
  - 900°C
  - Lightweight articulatable nozzle and gun assembly.
- Developed for demanding repair applications for shop and portable in-field repair applications.
- With licensed patent-pending technology from ARL, SDSM&T and UTRC.

Other Repair Examples

- TD-63 Valve Actuator Body – US Navy
  - Corrosion and sealing surface repair application
  - Path finder part
- Lessons Learned (Challenges)
  - Masking points
  - Inside corners



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Another Examples

- B1 False Axle
  - Repair of worn bearing surfaces
- Lessons Learned
  - Must account for needed overspray to allow for machining
  - Layer thickness not always easy to predict on large build-ups
  - Must deal with blending issues at interfaces of overbuilt areas

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One More Example

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- F-15 AMAD Housing
  - Access to internal features can be restricted by other areas of the part.
  - Building up a full width on a surface generally requires access above and below.

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Future Capabilities: 6-axis Cold Spray Repair Station

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- Equipped with a tool changer for both additive and subtractive processes, along with in process NDE (currently under development with OSD Mantech).
- Transitioning technology with local small business high-tech startups.

VRC METAL SYSTEMS

FLEXIBLE ROBOTIC ENVIRONMENT FIRST IN MODULAR ROBOTIC SYSTEMS

- Next generation "smart" repair capabilities…

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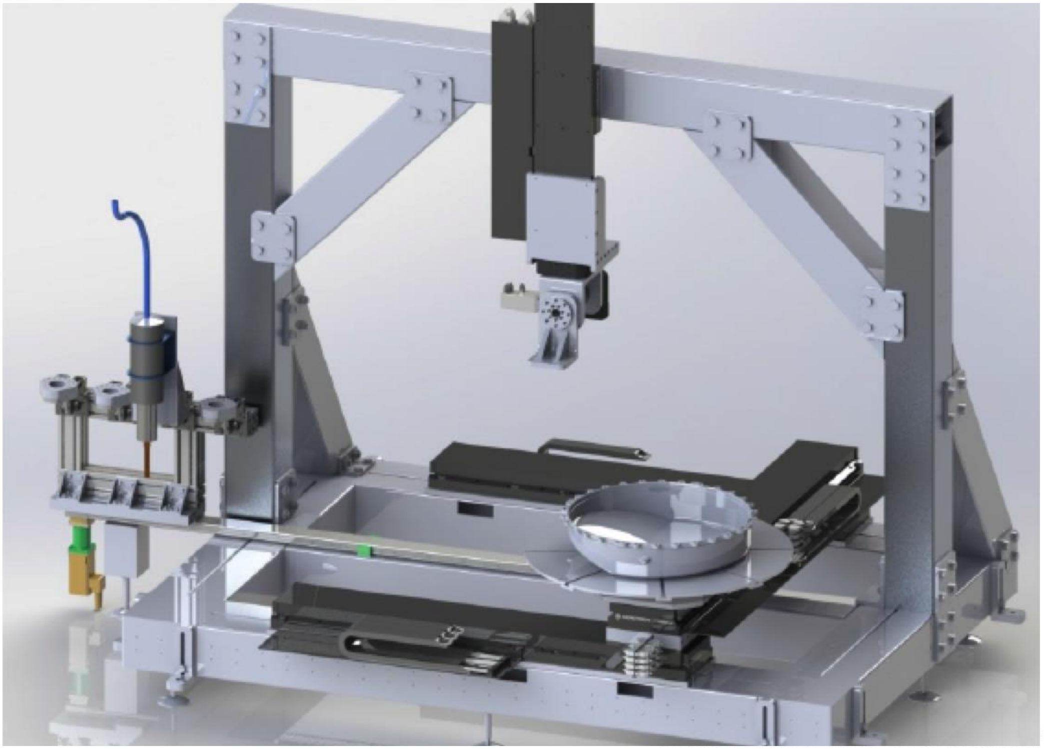

5' x 4' x 3' work envelope

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Summary

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1. Need SERVICE BASED qualification criteria, with realistic requirements, stressing timeliness not exhaustiveness. (Life Extension not a Fountain of Youth)

2. Repair risks MUST be compared to existing alternatives, NOT new pristine material. (Doing nothing may present much greater risk to the warfighter)

3. Need streamlined repair process of 180 days or less from need identification to fielded repair solution…(Opportunities exist RIGHT NOW to dramatically reduce lead times and improve system reliability and availability.)

Questions?

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