CURTISS WRIGHT
Surface Technologies


# Laser Peening for Nuclear Reactor Applications

**NRC Visit**

**February 3, 2015**

Metal Improvement Company
Subsidiary of Curtiss-Wright Corporation

Enhancing the performance of metals and materials

# Presentation Outline

- **Company Overview**
- **Laser Peening Benefits and Applications**
- **Beam delivery history, development, and current DGS**
- **Proposed tooling and mock-up implementation**
- **On Site Experience**
- **Q&A**

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# Curtiss-Wright Corporation History


**Tracing its roots to the Wright Brothers & Glenn Curtiss**

# Curtiss-Wright Corporation Today

- A multinational provider of *highly engineered products and services* for demanding markets
- Strong positions in diversified, niche markets built upon:
  - Engineering and technological leadership
  - Strong relationships with our Customers
- Organized into three market facing segments
- ~10,000 Worldwide Employees

**Commercial / Industrial**


**Defense**

**Energy**

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# Curtiss-Wright Segment Products & Services

**Commercial / Industrial**

- Surface Technologies
- Aerospace sensors and actuation
- Industrial controllers

**Defense**

- Defense electronic systems and controllers
- Naval propulsion pumps and motors

**Energy**

- Oil & Gas industry valves
- Power Gen Products & Services

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# What is CW Surface Technologies?

- Job Shop Providers of Surface Treatment Services
  - Multiple Premium Brand Names
- 74 facilities in N.A., Europe & Asia
- Technologies:
  - Engineered Coatings
  - Shot Peening
  - Laser Peening
  - Analytical Testing Services
- Quality Approvals facility dependent:
  - Nadcap-Accredited in Surface Enhancement
  - ISO9001, AS9100C, TS16949 and ISO13485
  - OEM and FAA approvals

Metal Improvement Company

E/M COATING SERVICES
ENGINEERED COATING SOLUTIONS

PCS Parylene Coating Services
A Division of Metal Improvement Company
"The first name in Parylene"

EVERLUBE® PRODUCTS

IMR TEST LABS

CCRS

GARTNER Since 1923

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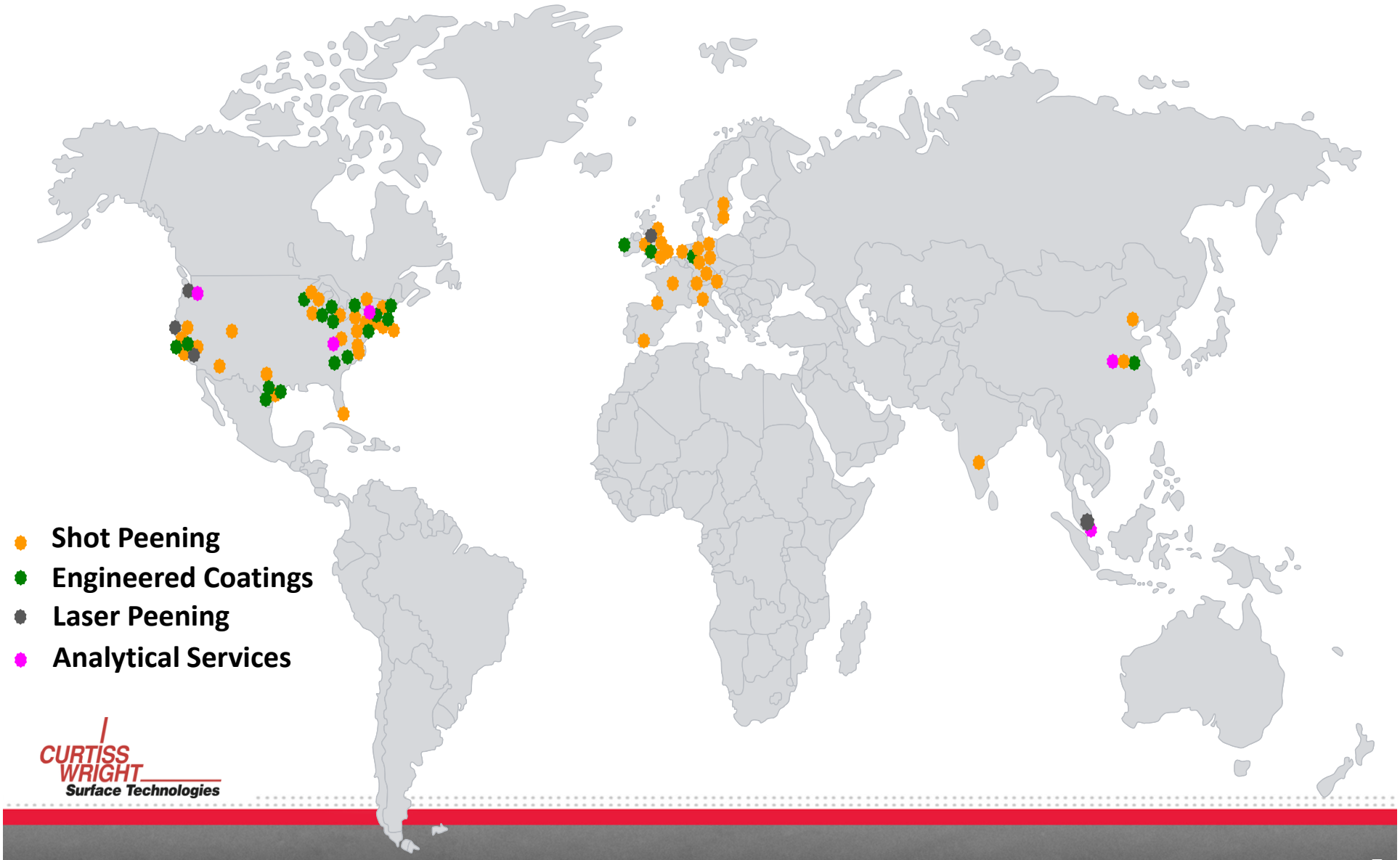
# CWST Global Facility Network

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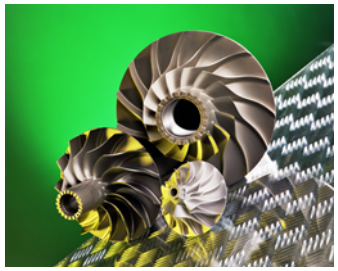
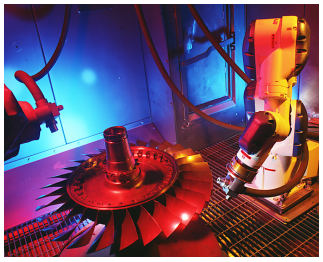
# Shot Peening

- **Facilities:**
  - 21 North America
  - 20 Europe & Asia
- **Capabilities:**
  - Shot Peening
    - Prevention of SCC, fatigue, fretting fatigue
  - Shot Peen Forming
    - Aircraft wing skins & distortion correction of large machined parts
  - On-site Shot Peening
  - Superfinishing
  - Architectural Peening
- **Specifications:**
  - AMS 2430
  - AMS 2432

Metal Improvement Company



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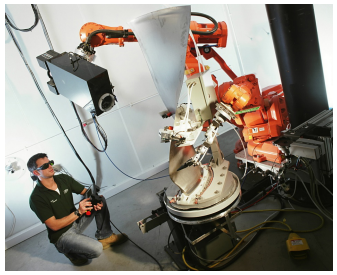
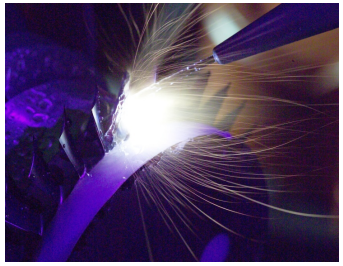
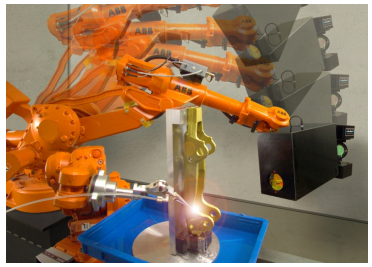
# Laser Peening

- **Facilities:**
  - Livermore, CA
  - Boeing – Frederickson, WA
  - USAF – Hill AFB, UT
  - Barnoldswick, UK
  - Singapore
- **Capabilities:**
  - Laser Peening of flight, industrial & steam turbine engine rotating components for:
    - SCC
    - Fatigue
    - Fretting fatigue prevention
    - F.O.D. durability
  - Laser Peen Forming of panels/structures
  - On-site Laser Peening
- **Specifications:**
  - AMS 2546







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# Analytical Services

- **Facilities:**
  - 3 North America (NY, KY & OR)
  - 2 Asia (Singapore & Suzhou)
- **Capabilities:**
  - Mechanical & Alloy Testing
  - Failure Analysis
  - Thermal Spray Coating Analysis
- **Markets**
  - Aerospace, Power Generation, Medical, etc.
- **ISO 17025, Nadcap and A2LA Medical Accreditations**
- **Major OEM Approvals**
  - Pratt, GE, Sikorsky, R-R, Boeing, Lockheed, Zimmer, Stryker, etc.

IMR TEST LABS

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# Engineered Coatings

- **Facilities:**
  - 14 North America
    - 4 Thermal Spray
    - 9 Solid Film Lubricants
    - 1 Parylene
  - 5 Europe
    - 3 in UK - Thermal Spray & Liquid Coatings
    - Germany – Solid Film Lubricants
    - Ireland - Parylene
  - 1 China - Solid Film Lubricant
- **Capabilities:**
  - Thermal Spray Coatings
    - TBC, MCrAlY, Ceramic & Carbides
  - Laser Cladding & PTA Weld Repair
  - Liquid "Spray & Bake" Coatings
    - Solid Film Lubricants
    - Zinc Flake Corrosion Resistant
    - Sacrificial Aluminum Coatings
  - Parylene Conformal Coatings

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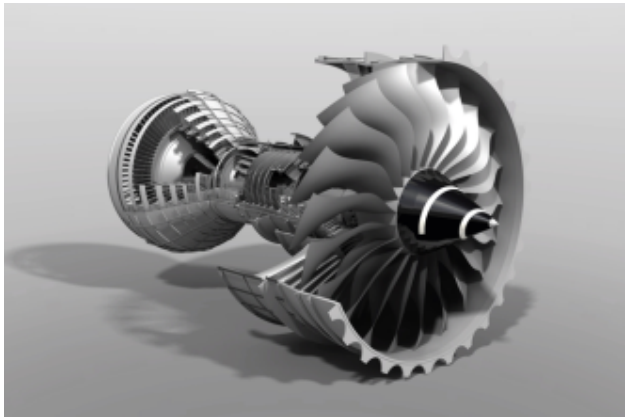

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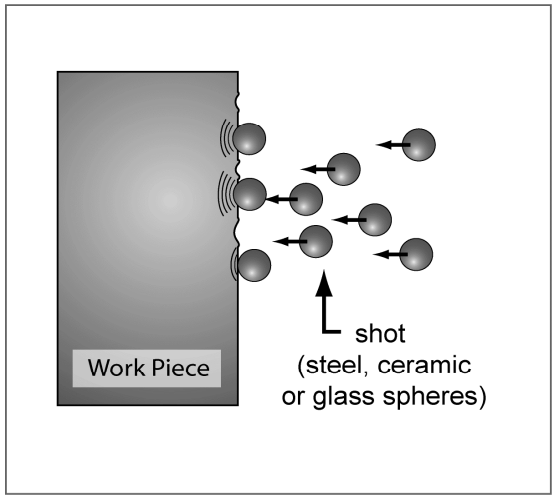
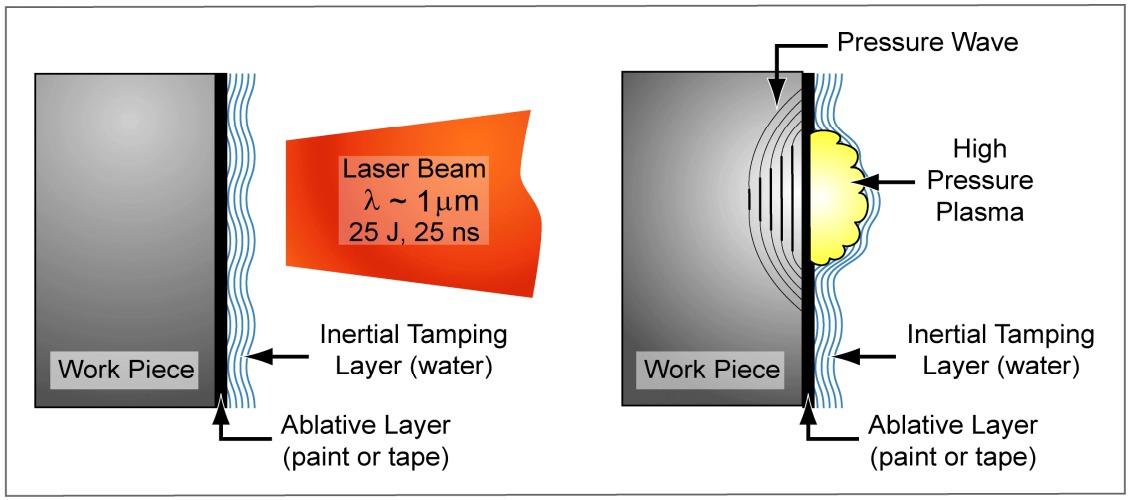
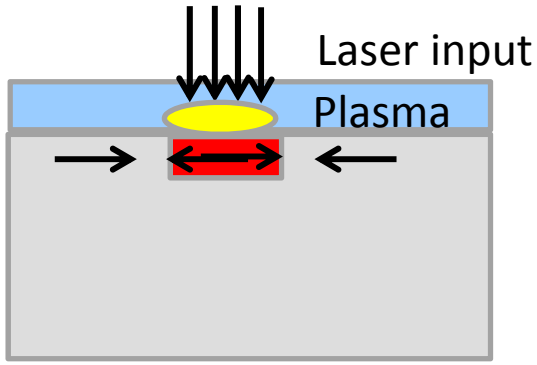
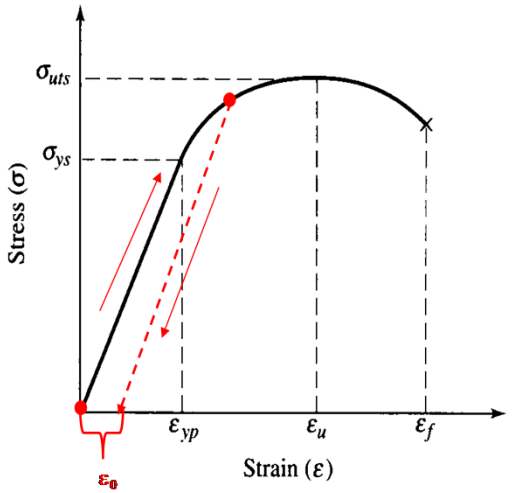
# Laser peening imparts compressive plastic deformation deep into a work piece




- **Plasma pressure plastically compresses metal in normal direction**
- **Metal expands transversely to conserve volume**
- **Surrounding material resists, setting up compressive field**

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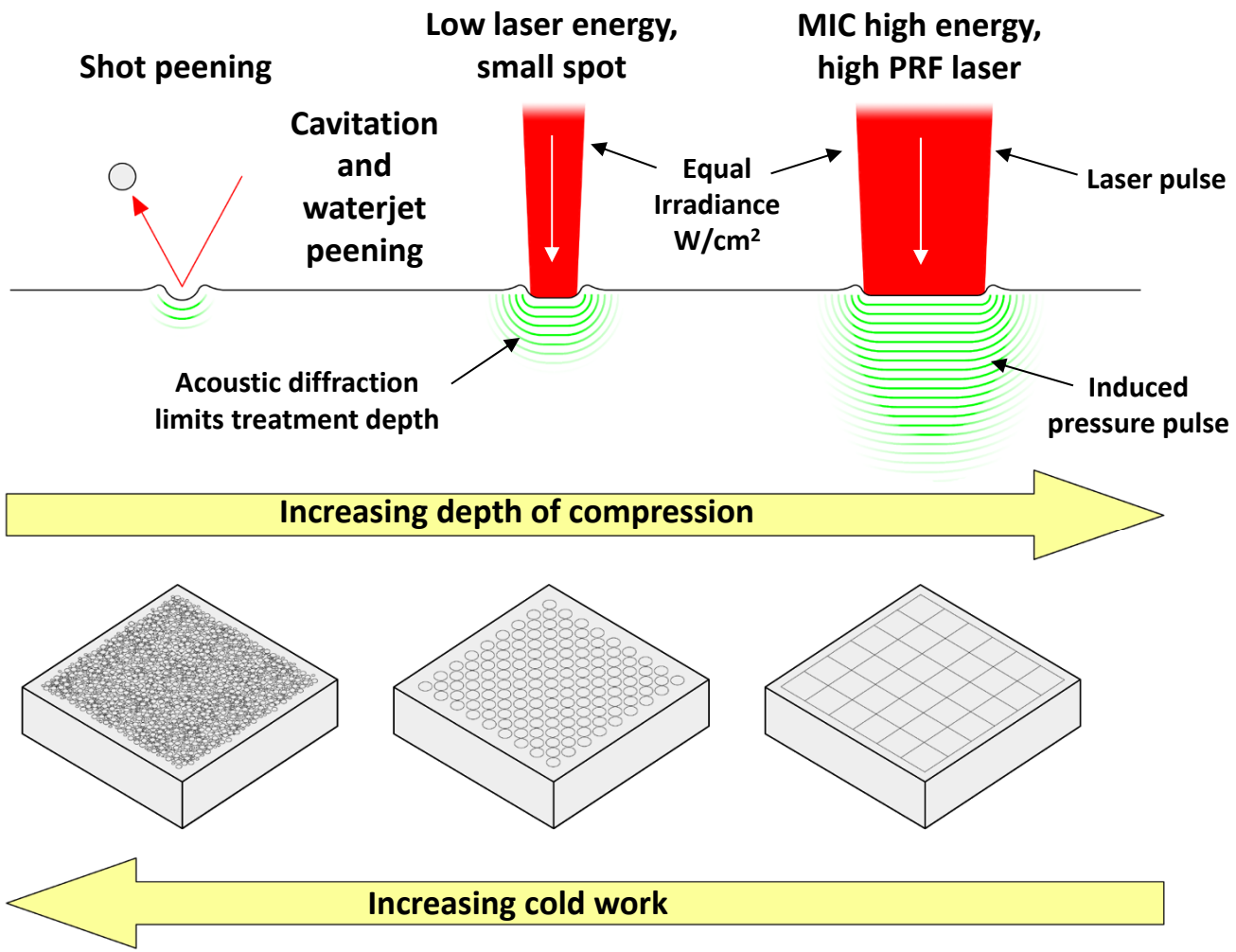
# Low energy, small spot size shares some disadvantages of shot peening

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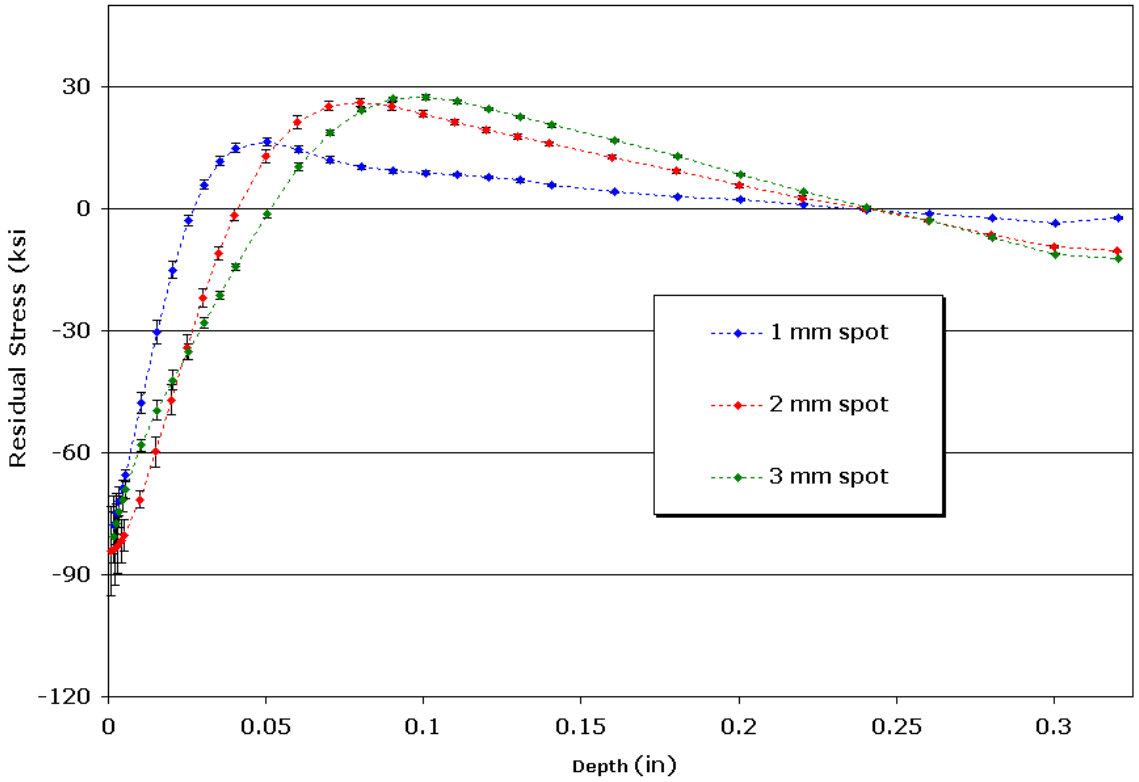
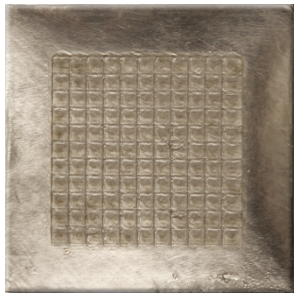
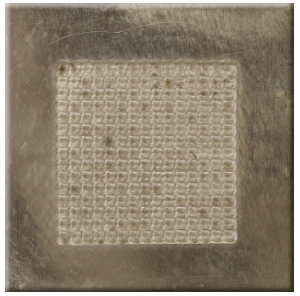
# The depth of compression significantly increases with spot size

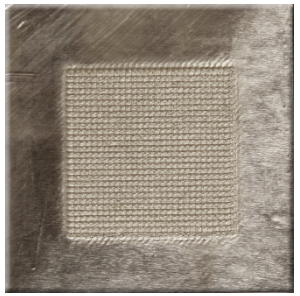


3mm spot pattern 16J/pulse



2mm spot pattern 7.1J/pulse



1mm spot pattern 1.8J/pulse

- Ti 6-4 test blocks laser peened at 10-18-2 show a >2X increase in depth of plasticity from 1mm to 3mm spot size

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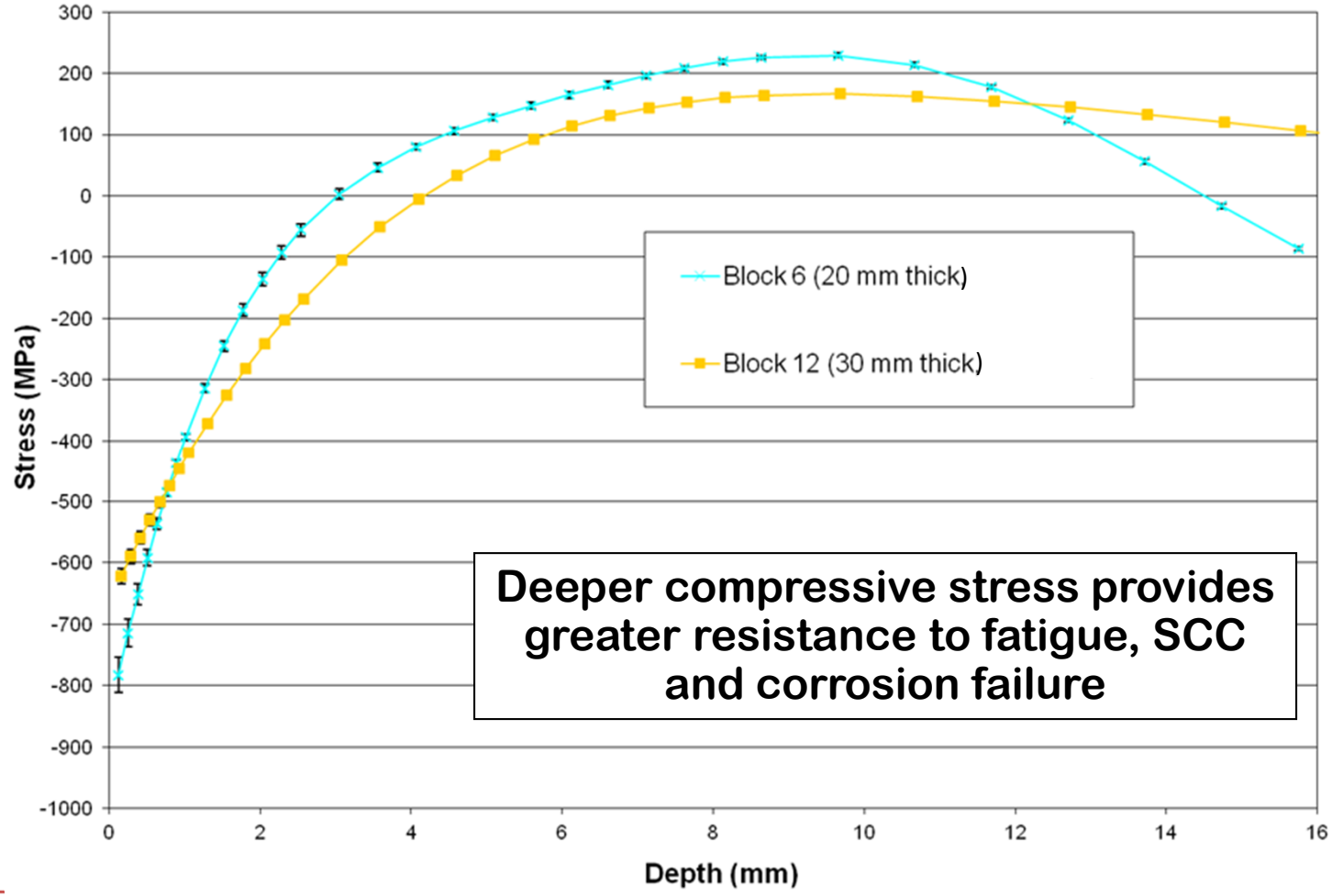
# Laser peening compressive residual stress in Inconel Alloy 22 penetrates to >4 mm




**Deeper compressive stress provides greater resistance to fatigue, SCC and corrosion failure**

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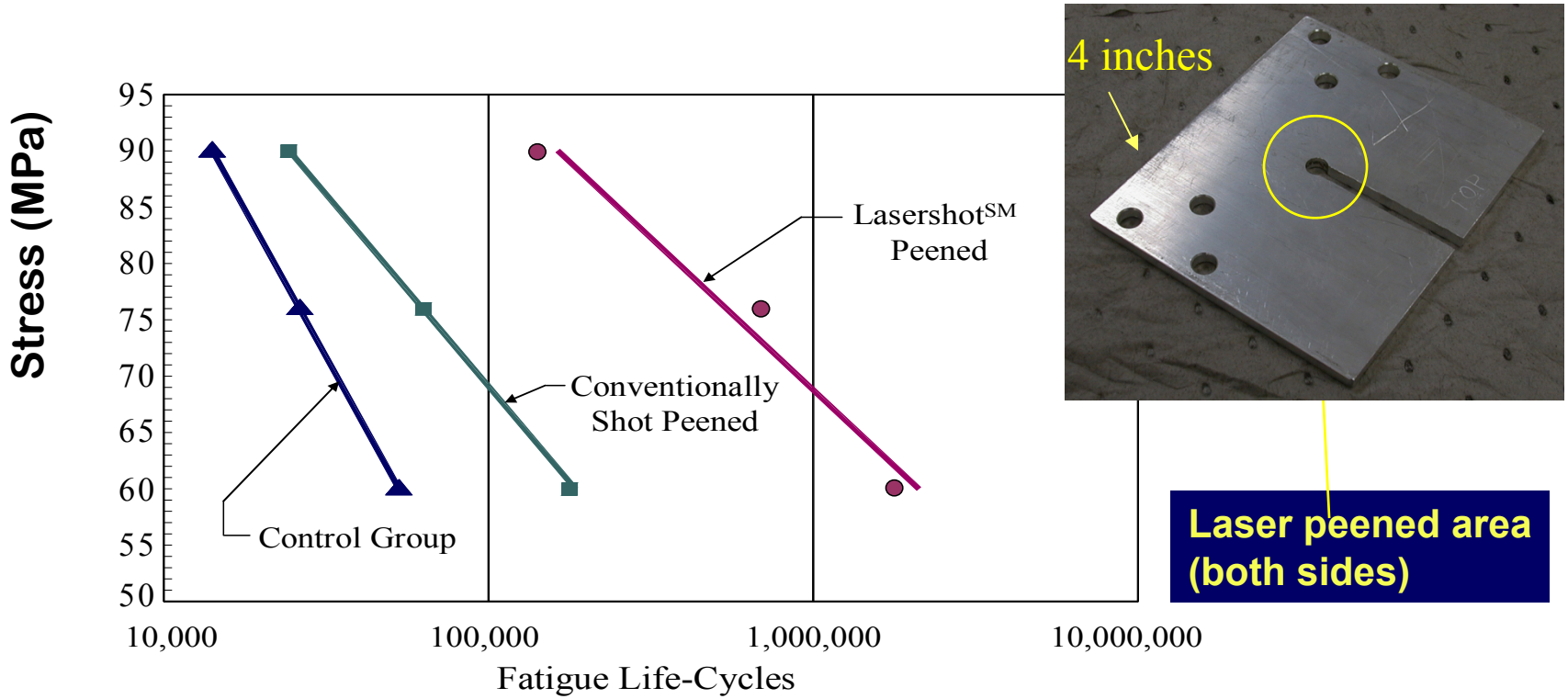
# Deep of stress enables as much as 10x fatigue lifetime improvement

**Laser peening offers a direct solution for fatigue problems;**
**Supports rapid deployment vs. lengthy redesign with inherent weight increase**




**6061-T6 Aluminum**

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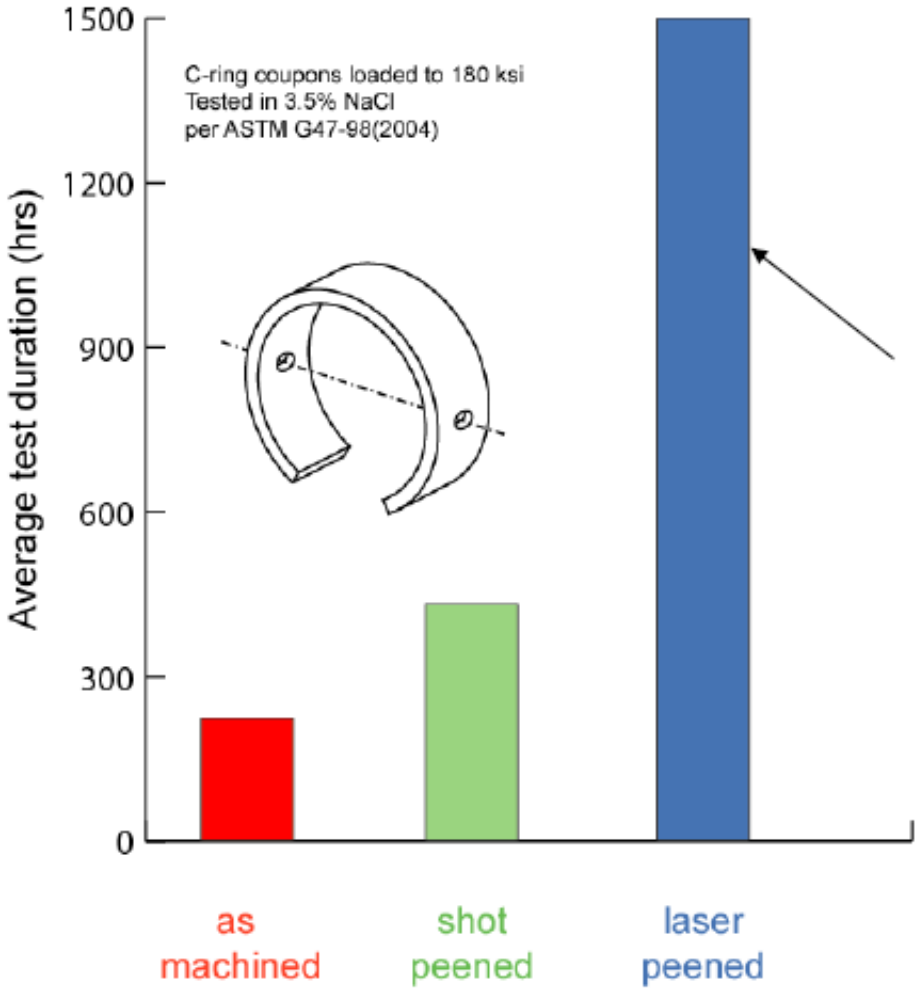
# Laser peening mitigates Stress Corrosion cracking in 300M Steel*

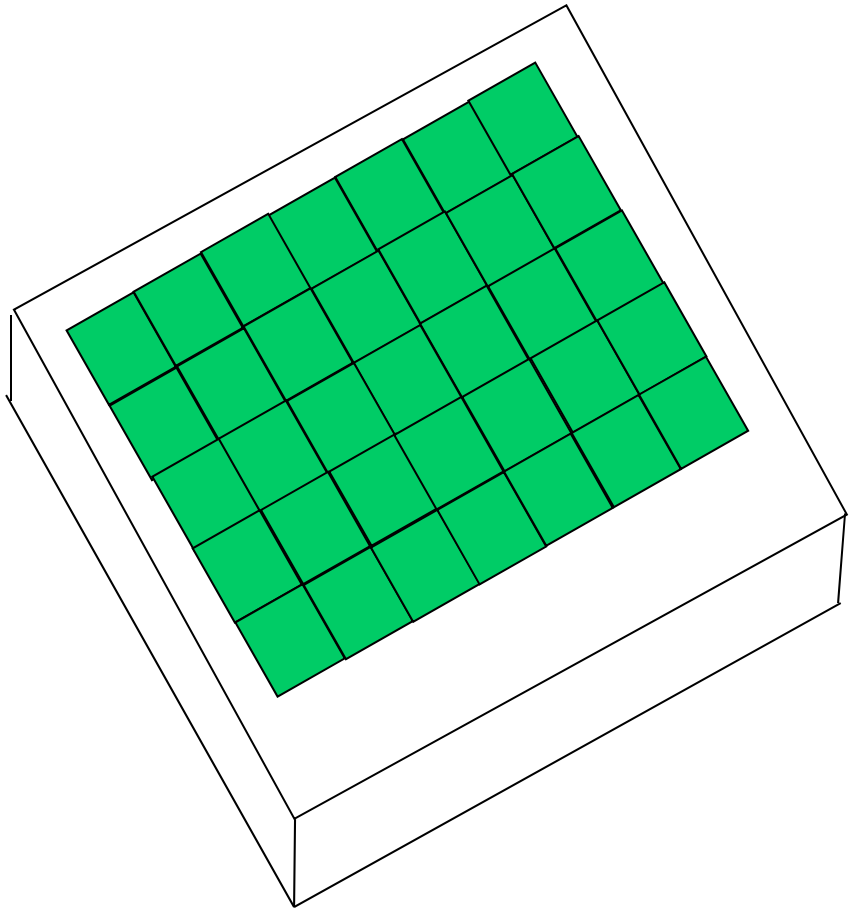



- Experiment terminated at two months
- Laser-peened coupons did not fail

* Data generated for MIC by T. Pistochini & Prof M. Hill

UCDAVIS

# Laser Peening coverage made easy by rectangular pulse footprint



**Rectangular, highly uniform laser beam intensity distribution is coupled to the part using an optical delivery system that preserves the uniform intensity. Peening pulses are applied sequentially in complete rows**

Pressure = P(GPa) = $1.02(I\ (GW/cm2))^{1/2}$

1 GPa = 145 ksi

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# Nd:glass laser provides enabling breakthrough in performance and reliability

- High energy peening pulses can be delivered up to 5Hz with very high beam quality
- High pulse energies are generated by a single laser amplifier
- Optical phase conjugation maintains *constant size, position, and pulse energy* for each peened spot, regardless of repetition frequency or run time
- Reliability has been demonstrated by continuous 3-shift operation with up to 500k processing shots per week from each system

Available "up time" readily exceeds 97%; unprecedented for this class of laser system*

*Based on detailed production shutdown reports 1/1-10/31/04

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# Laser peening extends lifetime of jet engine blades by > 20x


**Over 35,000 blades have been treated for engines powering Boeing 777s , A340s, G-VI and the new Boeing 787 Dreamliner**

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# Current applications of Laser Peening; Reliable and cost effective process

- MIC's production laser peening (LP) began in 2002
- Significant applications now in production
  - Trent 800 fan blades for Boeing 777
  - Trent 500 fan blades for Airbus A340
  - BR710 fan disc for Gulfstream V
  - Trent 1000 blades for Boeing 787 Dreamliner
  - Laser forming of 747-8 wing panels
  - Gas turbine blades for major OEMs
  - Steam turbine blades for major OEMs
  - Fan blades and IBRs for military application
  - F-22 wing attachment lugs – USAF, Hill AFB
- Each application supports savings in operational costs and/or performance enhancement

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# First 787 aircraft are powered by Trent 1000 engines with laser peened fan blades

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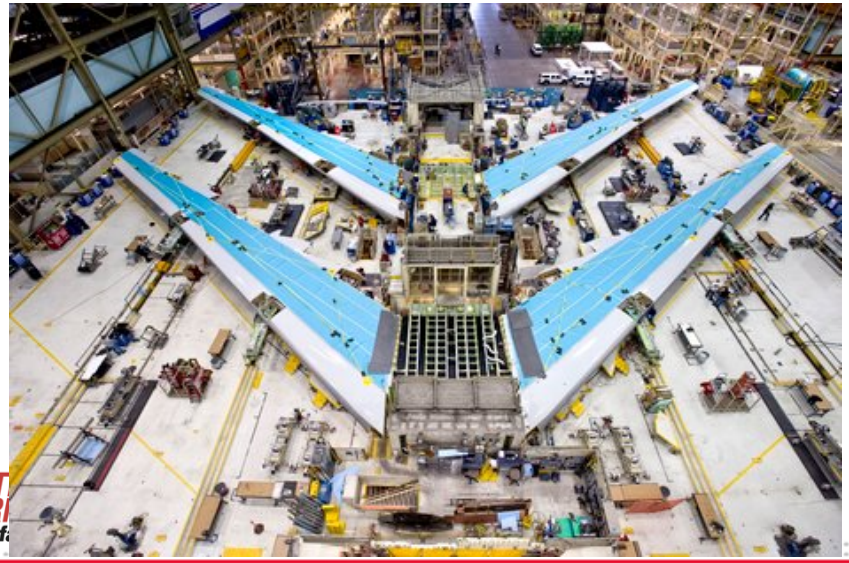
# MIC laser peening forms thick sections of wing panels for the new 747-8

Wing skin panels are in routine laser peen forming production

World's first aircraft with laser formed panels delivered 2011

# Laser peening enables efficiency and lifetime increases for gas and steam turbines

- Requirements for improved efficiency pushes blade size and hence stress loadings
- Laser peening enhances fatigue lifetime and reduces blade erosion

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# To be operative, Stress Corrosion Cracking requires three elements

For a stress corrosion crack (SCC) to propagate requires:

1. Material susceptible to corrosion (i.e. Grade A ship steel)
2. Corrosive environment ( i.e. salt spray)
3. Tensile stress (weld fusion and heat affected zones)

Use of corrosion resistant materials can be very expensive – too expensive to implement

Corrosive environment usually comes with the application – cannot change the needed application

Thus: Elimination of tensile stress can be the most cost effective way to minimize SCC

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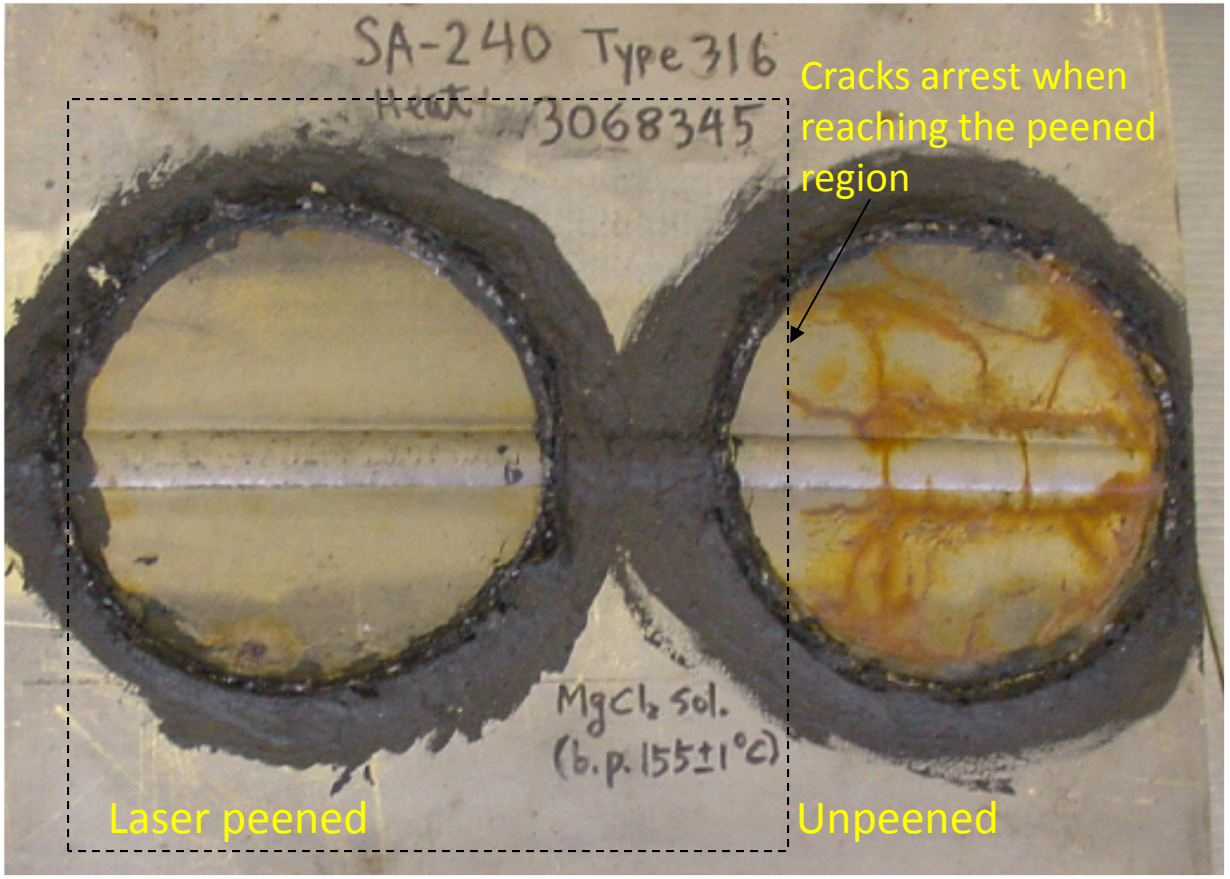
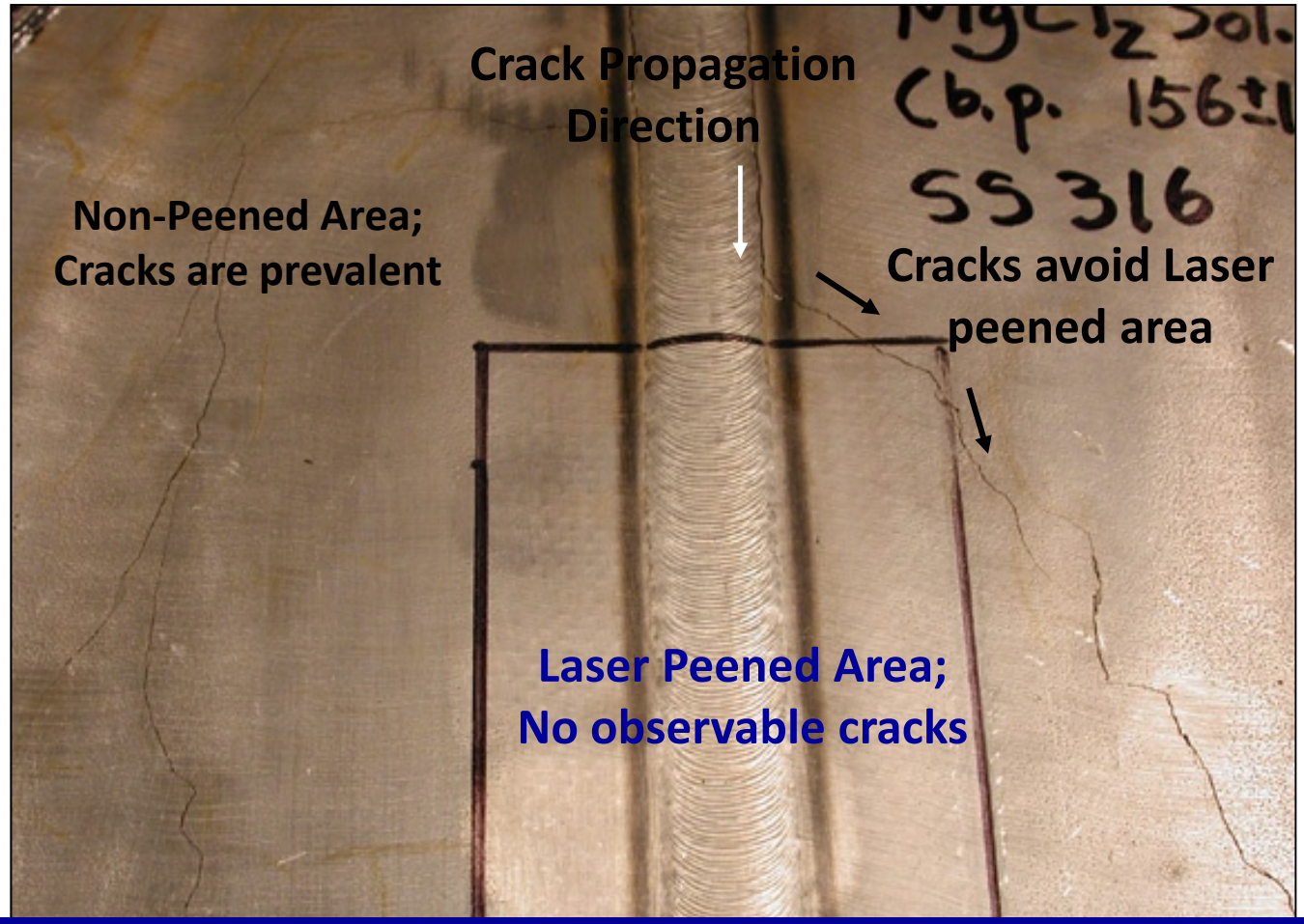
# Example: Laser Peening retards stress corrosion cracking in 316 SS




- Laser peened area is free of stress corrosion cracks and rust, in dramatic contrast to unpeened area

# Stress corrosion crack cannot penetrate into laser peened region of 1 inch thick weld

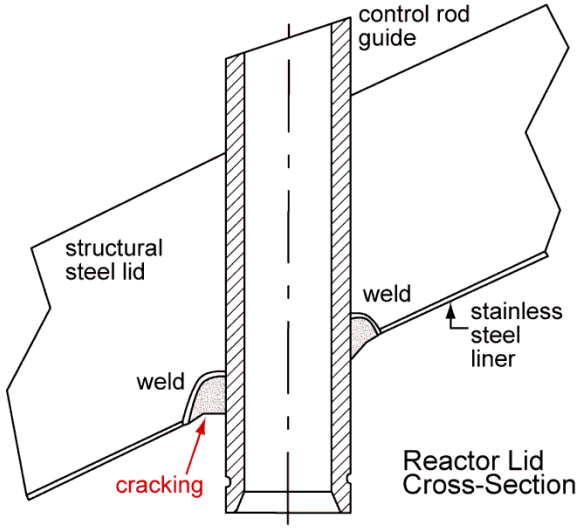
Specimens bathed in 40% solution of $MgCl_2$ at 160°C



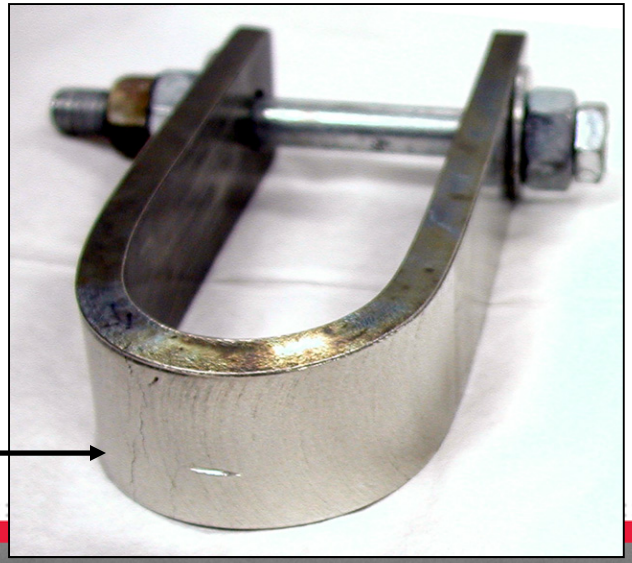

**Stress corrosion crack through 1 inch thick welded 316 stainless does not propagate into laser peened area**

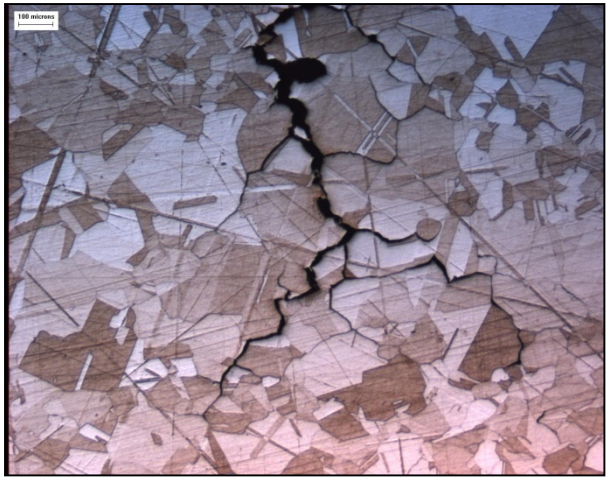
# U-bend tests of Alloy 600; Laser Peening of Nuclear Reactor Vessels

- Stress corrosion cracking around welds in pressurized water reactors has led to costly shutdowns, and reduced safety
- Welded material (Alloy 600) cracks readily in room temperature thiosulfate solution under sufficient tensile residual stress




Alloy 600 U-bends suffer from intergranular stress corrosion cracking in about 24 hours





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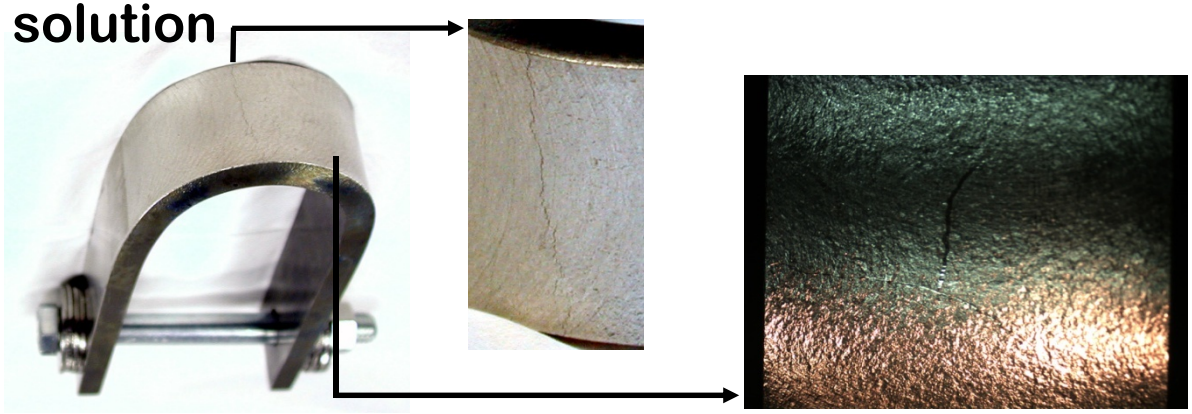
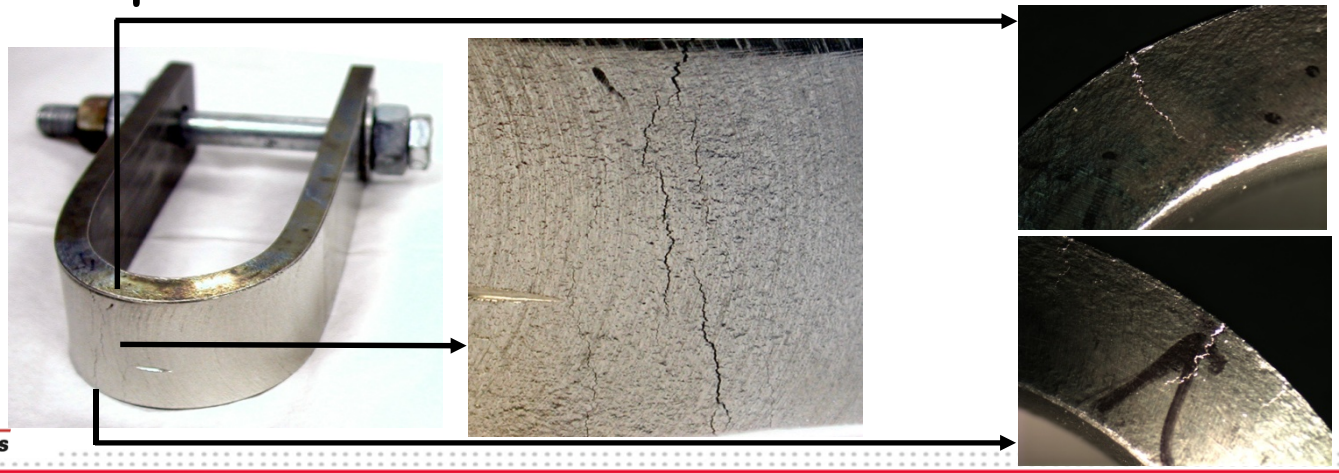
# Room temperature stress corrosion cracking of Alloy 600

Hairline cracks develop on the outer surface after one day in the thiosulfate solution



Cracks propagate quickly toward the inner surface with continued exposure



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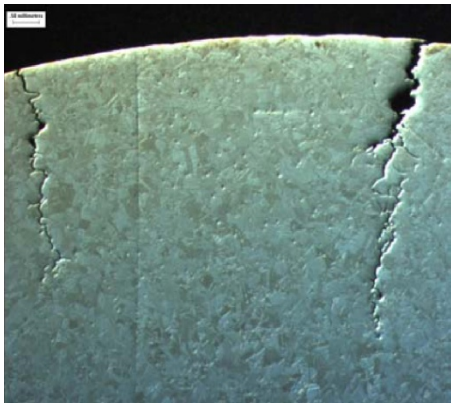
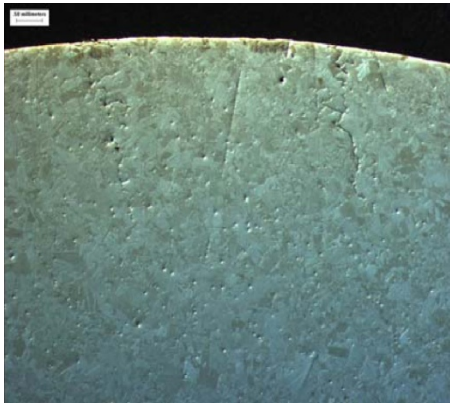
# Laser Peening dramatically reduces stress corrosion cracking in Alloy 600

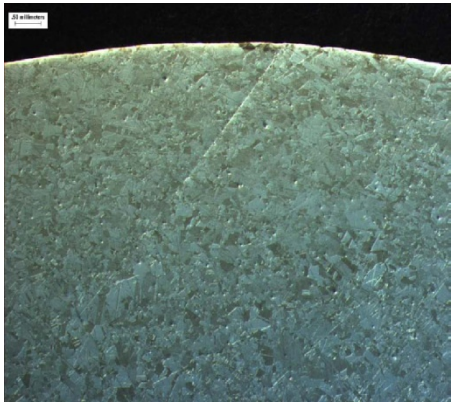
**U-bend samples tensioned and exposed to Thiosulfate to enhance SCC**



**Pre-cracked, no laser peening → Extensive Cracking**



**Pre-cracked, then laser peened → Cracking arrested**



**No pre-cracking, laser peened → No Cracking**

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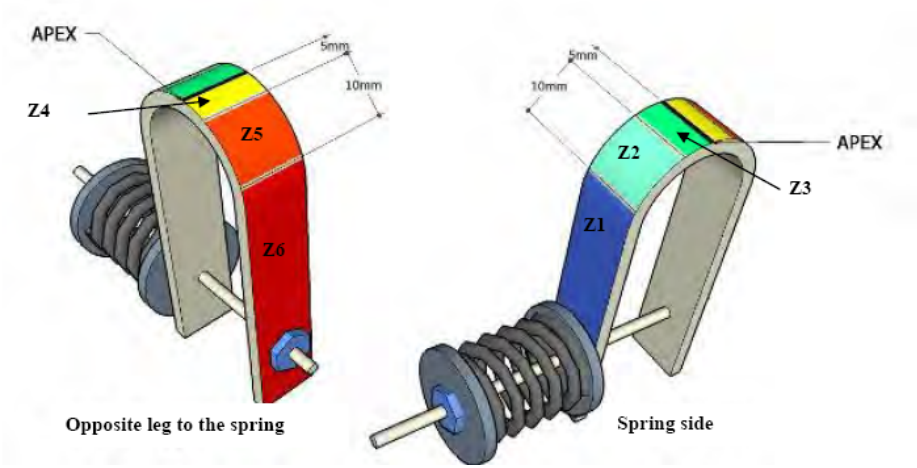
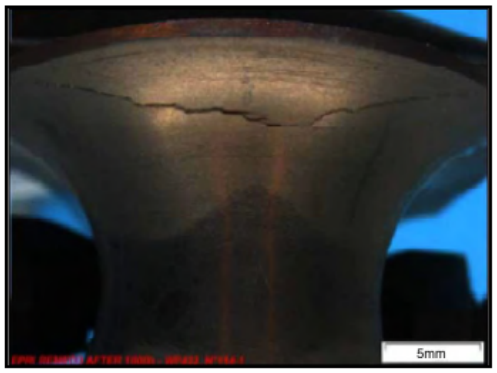
# Laser peened U-bends of Alloy 182 did not crack after 3000 hours – EPRI test




**RUB from steam generator tube cracks after 1000 h exposure – basis for comparison**

**Results: 1000 + 2000 h exposure of Alloy 182 U-bends**

| | | | | | | |
|---|---|---|---|---|---|---|
| HG + Air Laser Peening (MIC) | 3 mm | spring | UB-ALP-1 | No | No crack | No crack |
| | | | UB-ALP-2 | No | No crack | No crack |
| | | | UB-ALP-3 | No | No crack | No crack |
| | | | UB-ALP-4 | No | No crack | No crack |
| | 3 mm | bolt | UB-ALP-5 | No | No crack | No crack |
| | | | UB-ALP-6 | No | No crack | No crack |
| | | | UB-ALP-7 | No | No crack | No crack |
| | | | UB-ALP-8 | No | No crack | No crack |
| | | | UB-ALP-9 | No | No crack | No crack |

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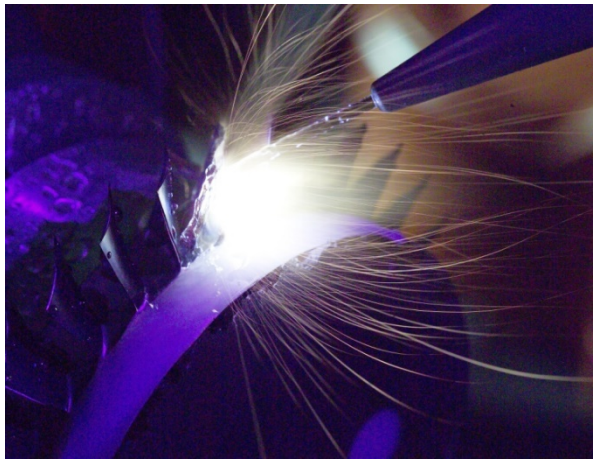

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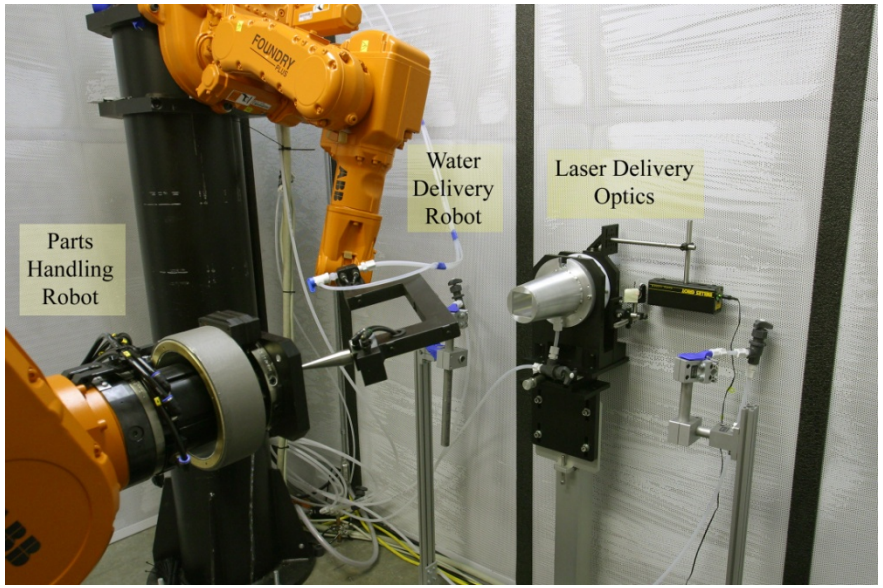
# A small component can be moved through a stationary beam




- Fixed beam automation system moves the part through the laser beam
- Production robots routinely handle components with weights >100kg

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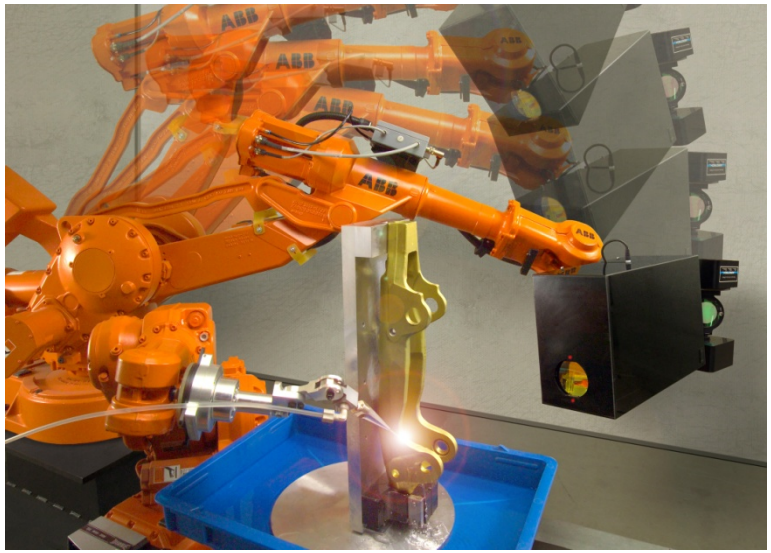
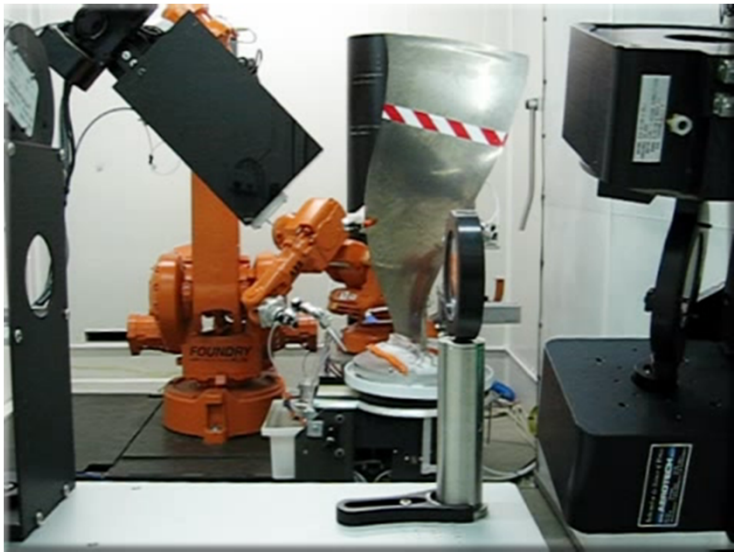
# A moving beam system allows larger components to be peened




- The robot holds a laser delivery tool instead of the component
- High speed gimbals keep the high power beam aligned to the scanning delivery tool
- Palletized robot system allows straightforward transport and setup at the processing site

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Surface Technologies

# Beam scanning allows very large panels to be processed

An overhead gantry transports wing skins through a fixed processing cell; the laser propagates ~150ft between the trailer and the cell.

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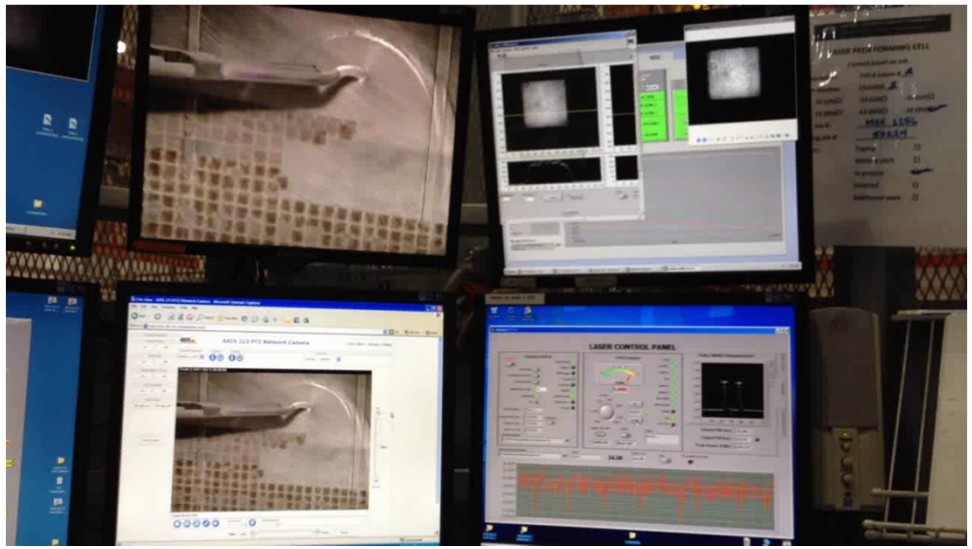
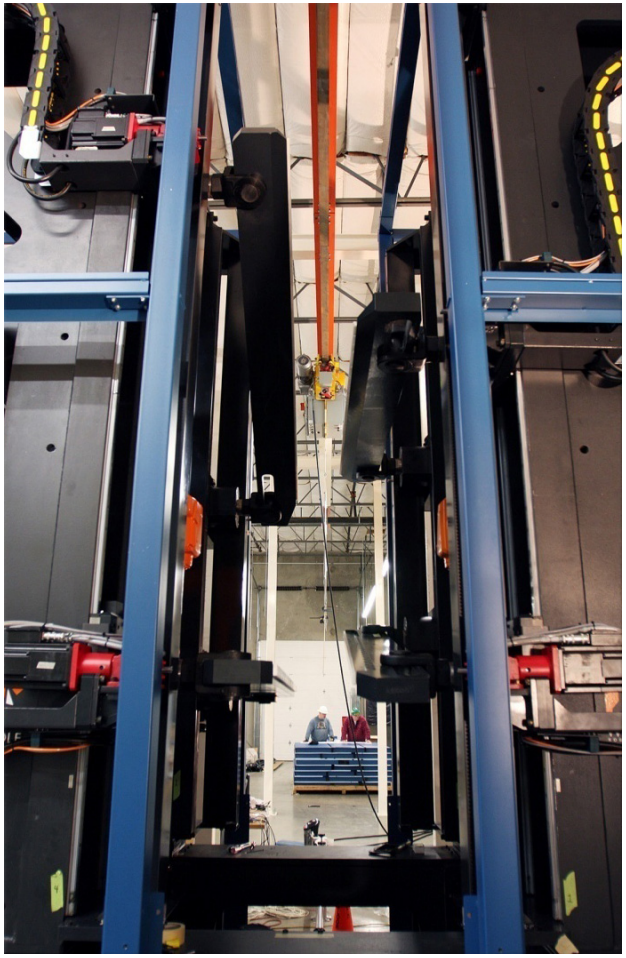
# Decoupling beam scanning from robot motion can improve process efficiency




Laser peen-forming with 8.5mm spots at ~4Hz

A typical wing panel is 105’ long, up to 25mm thick, and requires ~200k laser shots



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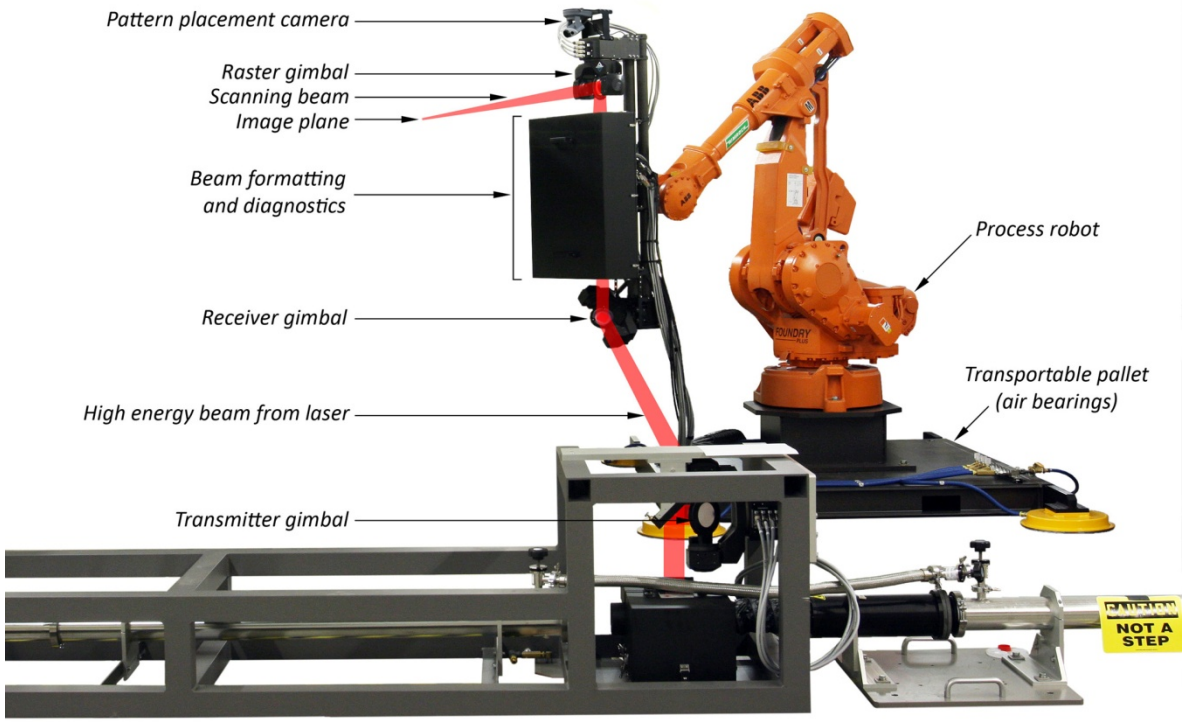
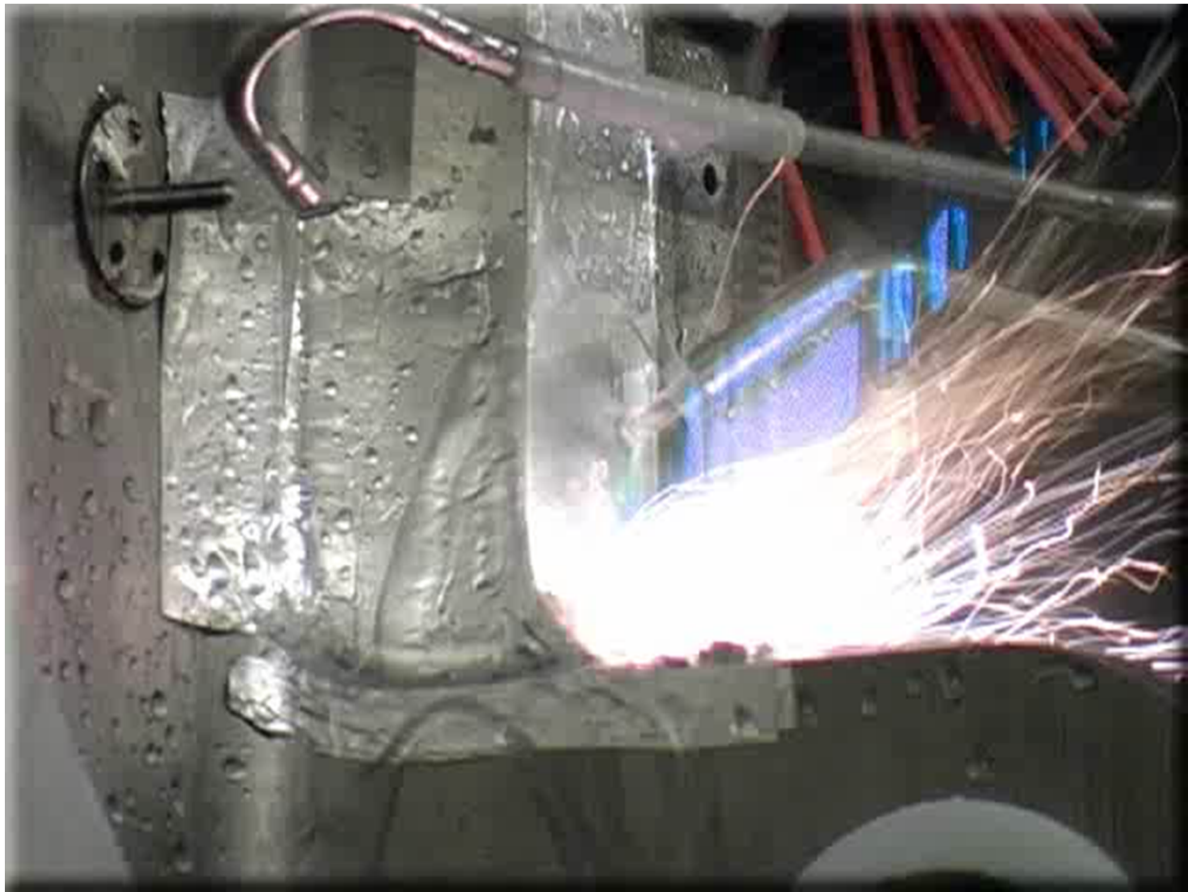
# Dual-gimbal stinger was developed for on-site laser peening of large components




- Complex spot patterns can be delivered from a single robot position

# The DGS is a proven beam delivery technology



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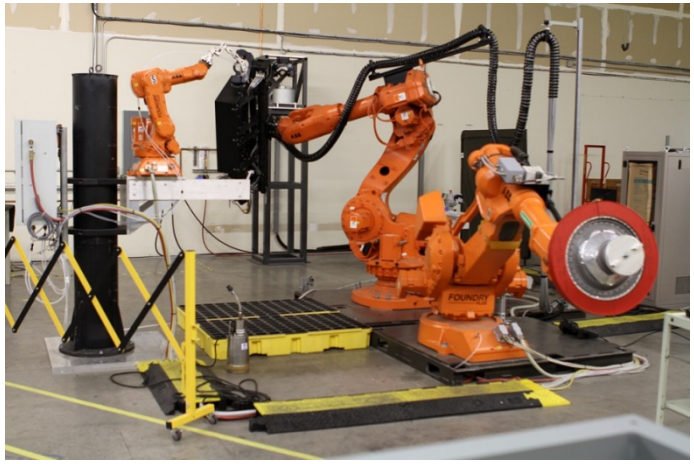
# Presentation Outline

- Company Overview
- Laser Peening Benefits and Applications
- Beam delivery history, development, and current DGS
- Proposed tooling and mock-up implementation
- On Site Experience
- Q&A



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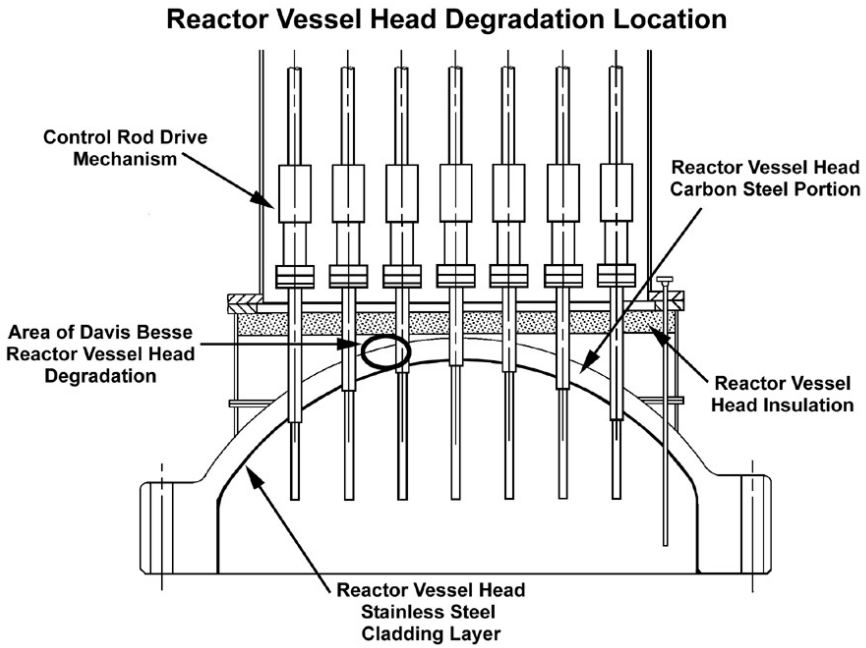
# Laser peening can mitigate tensile weld stresses in nuclear reactors

## Technology can be applied to existing and new reactors




- Stress corrosion cracking can be virtually eliminated by laser peening areas of tensile stress.
- Transportable system and beam delivery technology can deliver laser peening inside reactor containment building and in vessel

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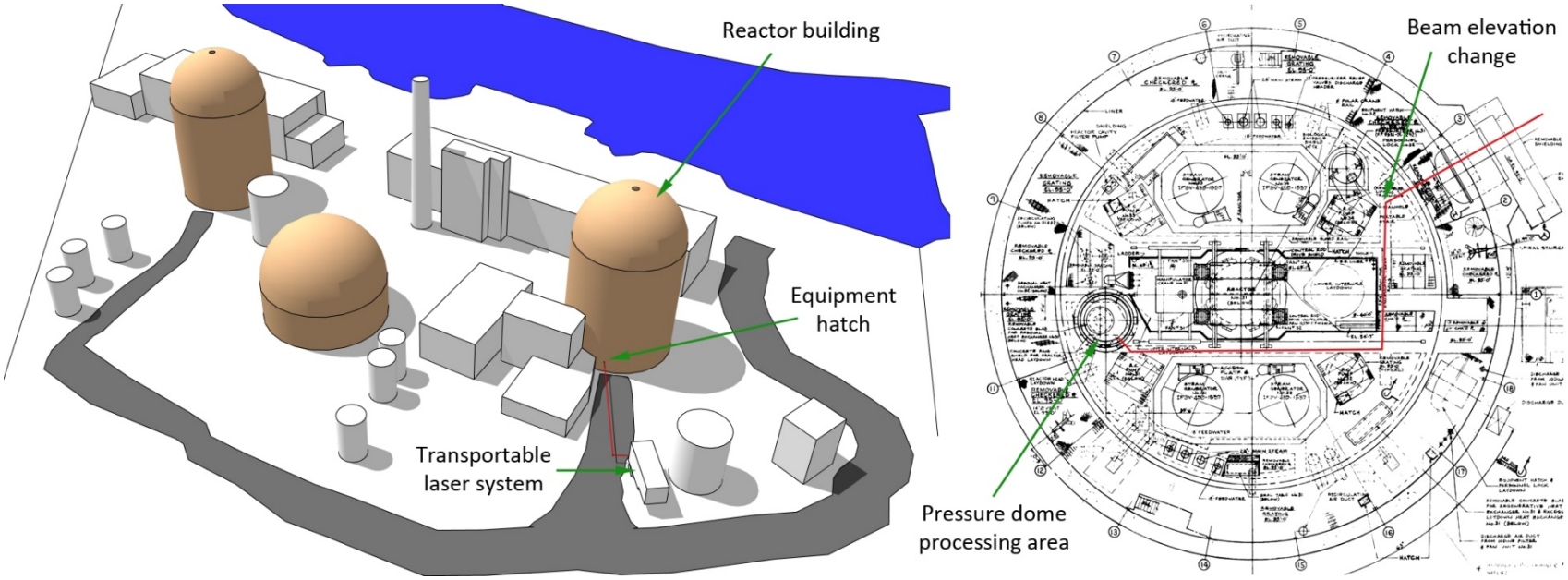
# Laser peening in a containment building is an extension of previous challenges




**Long path high-laser-beam delivery is similar to that needed for 747-8 wing panel forming and laser-peening of the F-22**

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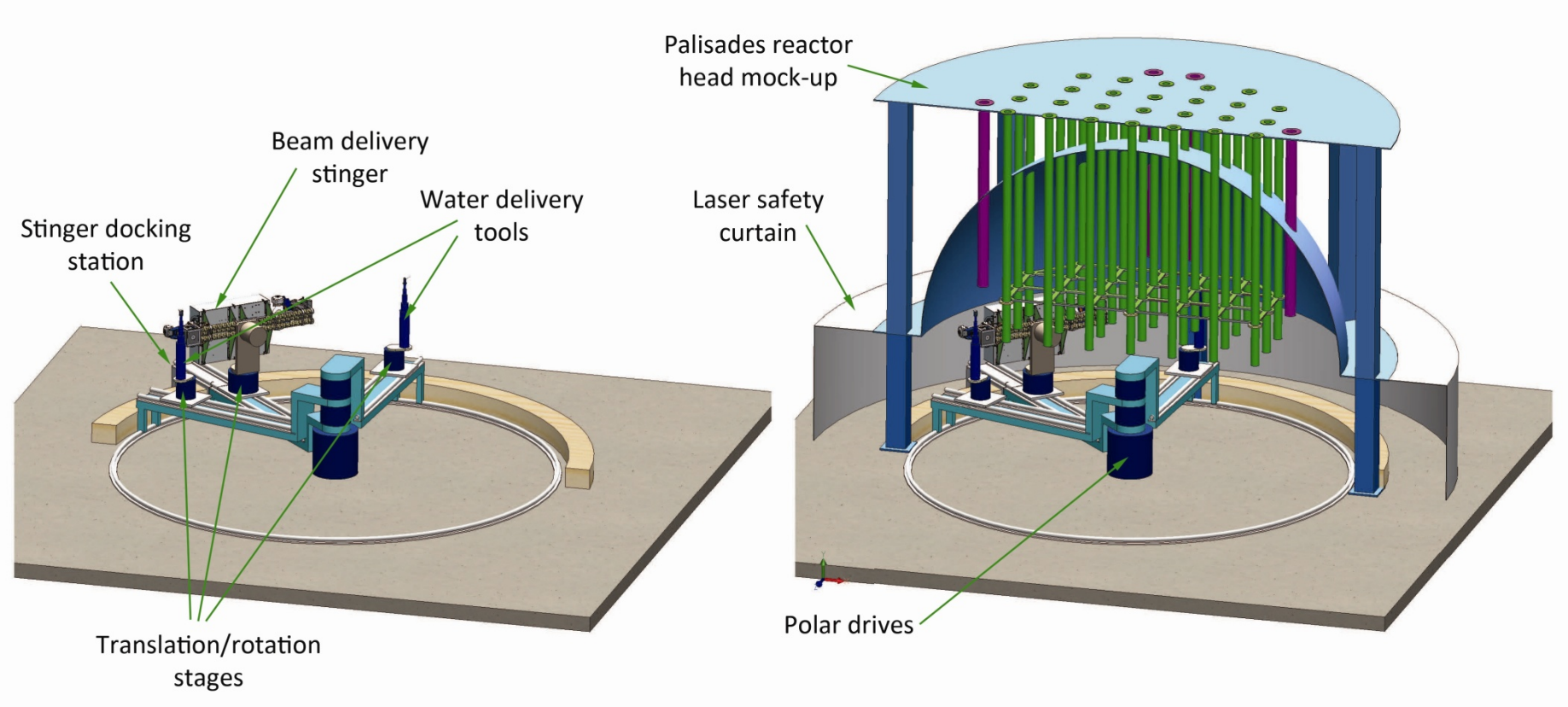
# A polar-coordinate stage can provide positioning for the dual-gimbal-stinger




**Custom beam delivery system reaches the perimeter of each CRDM J-weld in the head laydown storage location**

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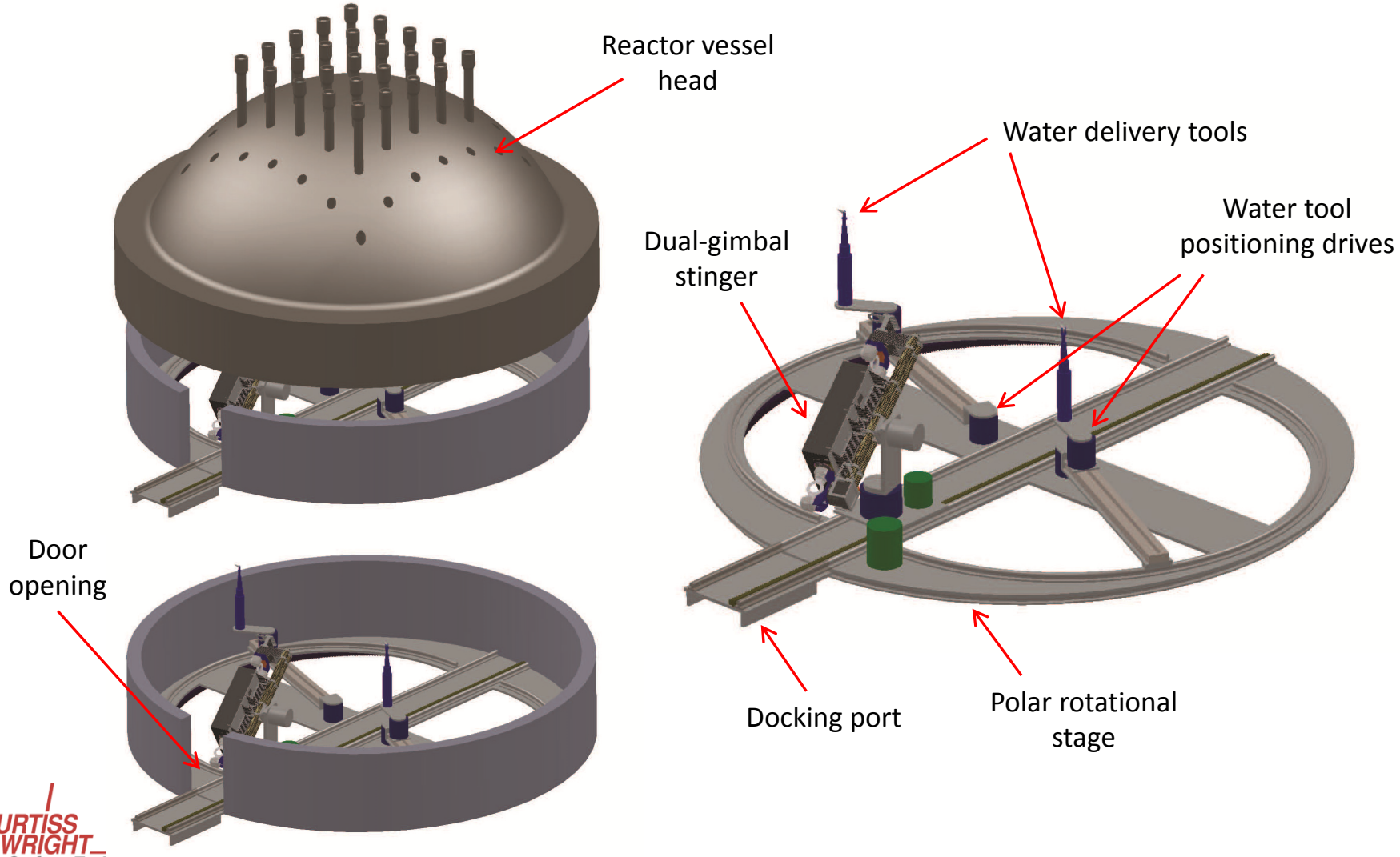
# Current design of the polar coordinate beam delivery system

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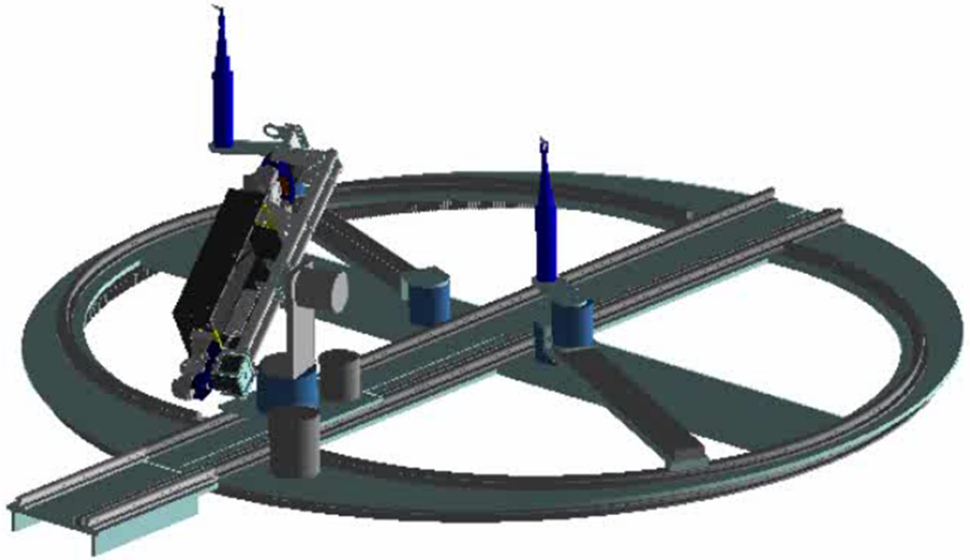
# Demonstration of the laser peening process on a single J-weld



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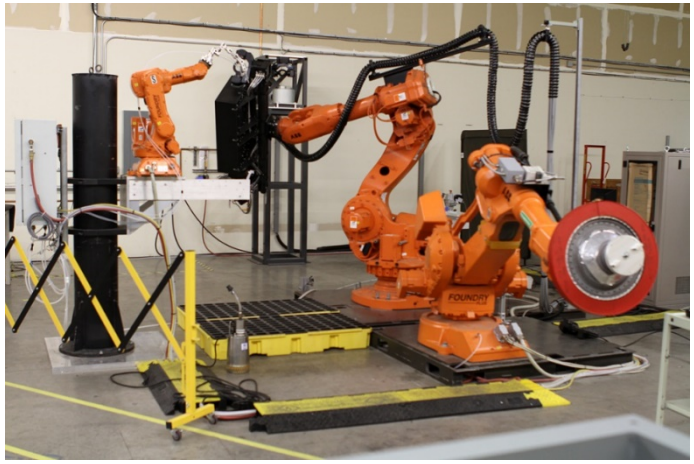

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# Extended history of on-site laser peening

- MIC fielded its first laser peening capability outside of Livermore in 2003
- Commercial laser peening is in full commercial production at five sites around the world, including Livermore
- Three of those use the MIC transportable laser design at a customer site
- Each transportable system is located at the customer's site and require remote beam delivery of up to 150'


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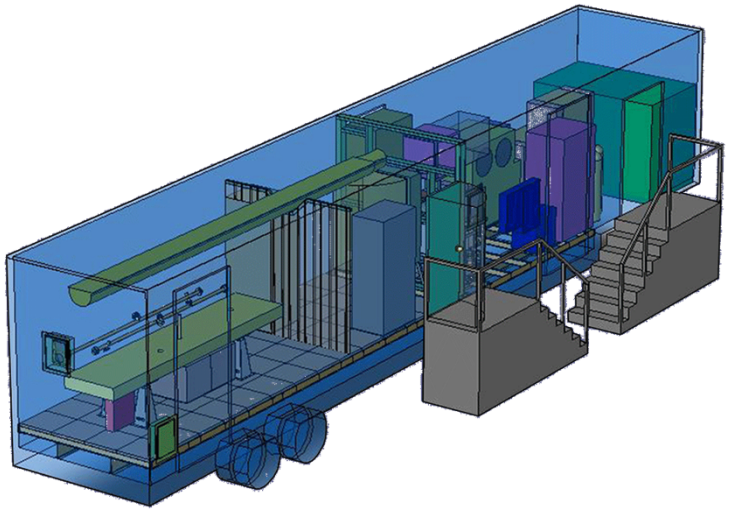
# Four transportable laser peening systems are fully operational




- Allows rapid deployment anywhere in the world
- Completely self-contained, system needs only one electrical connection
- System can be located outside existing facilities with beam piped in to delivery robot for application

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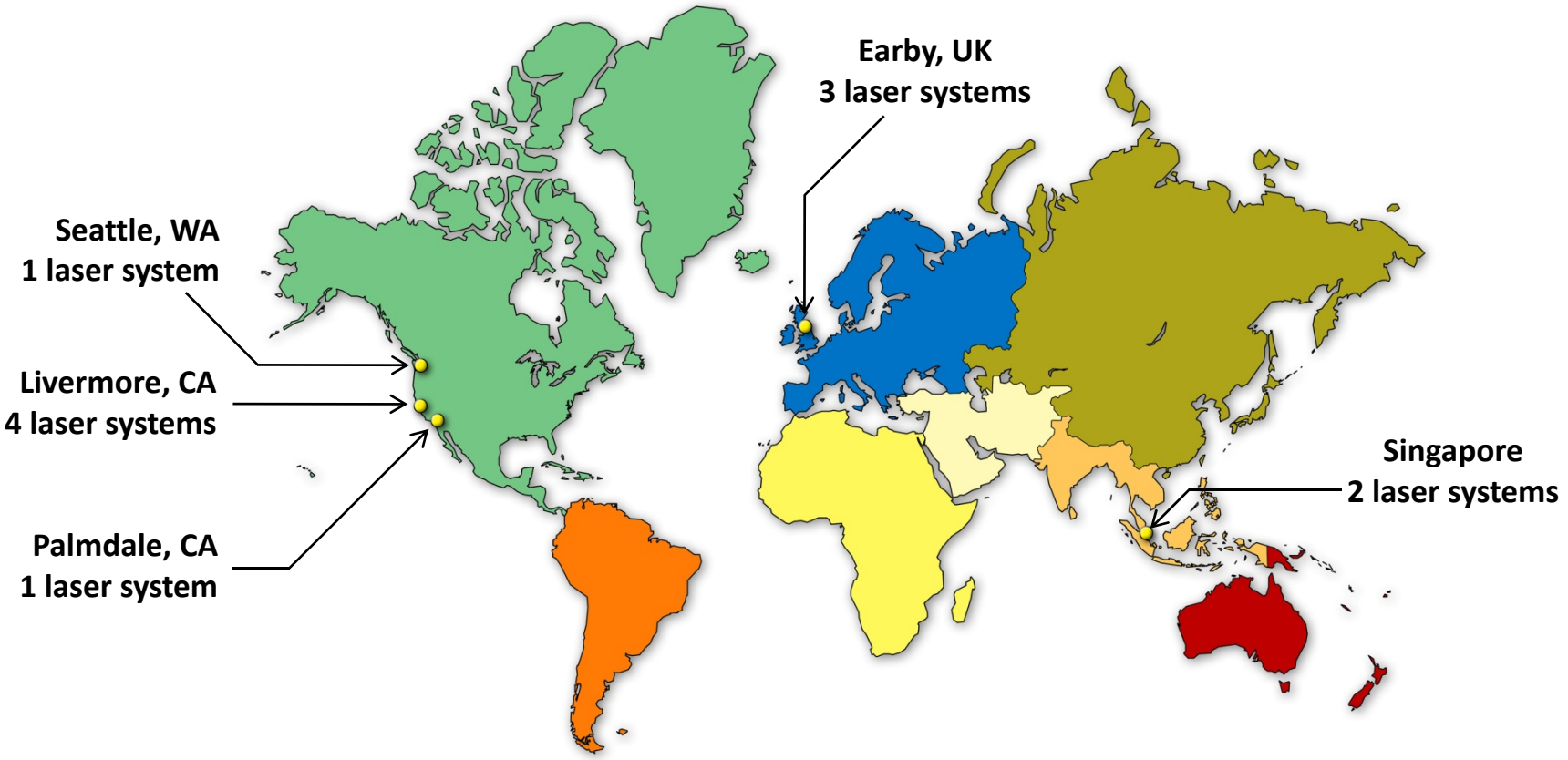
# MIC laser peening is deployed around the world

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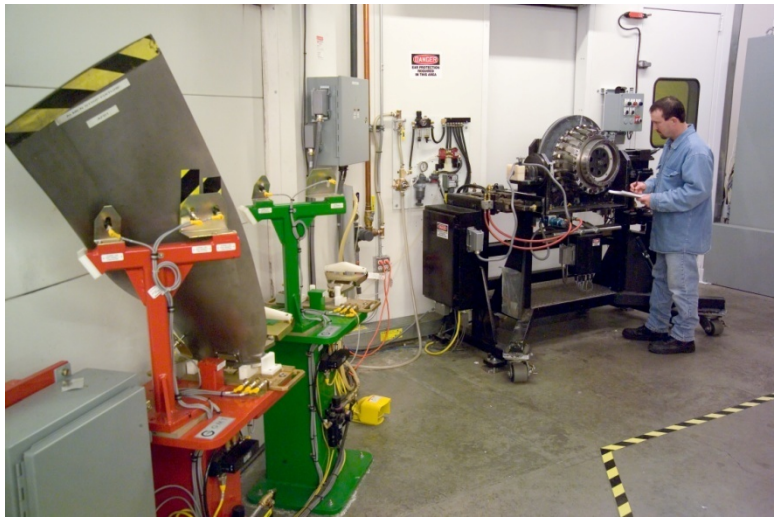
# Livermore supports production peening, new equipment, and R&D



**MIC Livermore, CA**

- **4 laser systems (1 transportable)**
- **3 fixed beam cells**
- **2 moving beam cells (hybrid – fixed or moving)**
- **1 dual-gimbal rastering cell**

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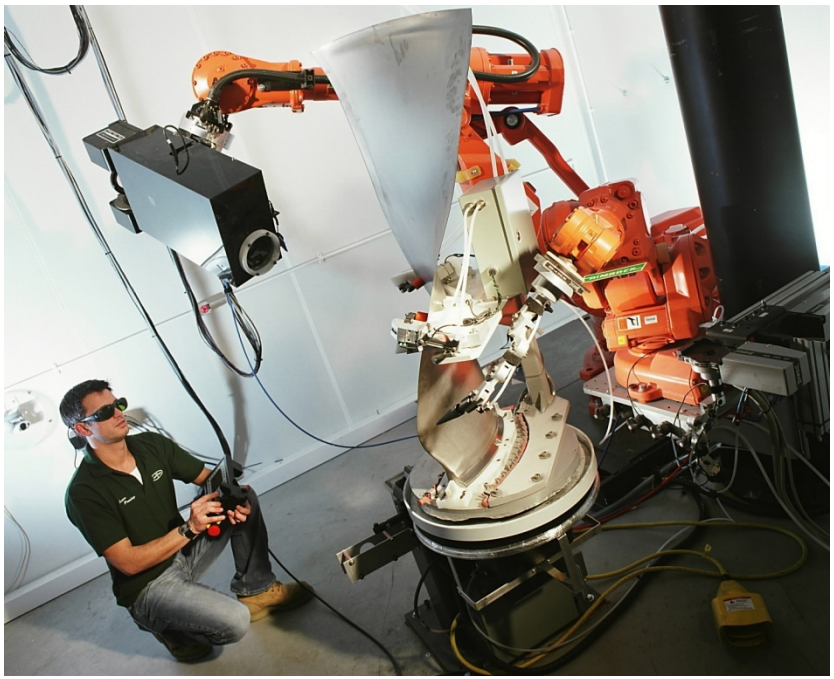
# MIC Earby, UK – OEM aerospace



**MIC Earby, UK**

- **3 laser systems**
- **4 fixed beam cells**
- **1 moving beam cell**

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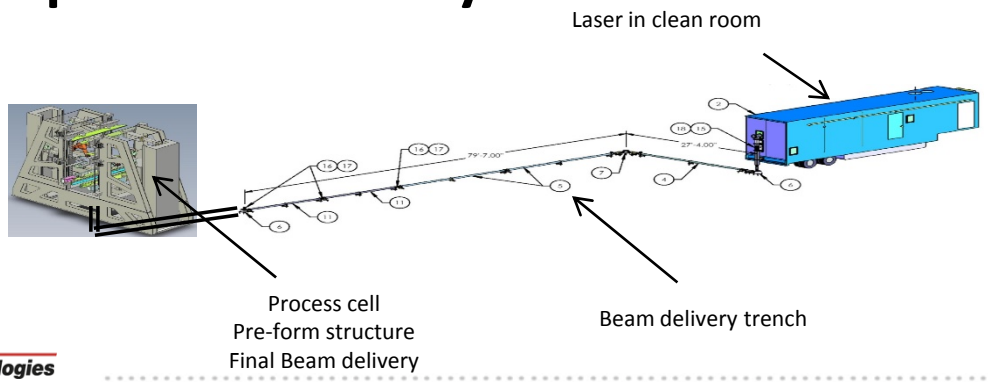
# Frederickson, WA – laser peen forming

- Boeing Fabrication plant
- Laser Peen Forming wing panels for 747-8 production
- 150 feet beam delivery to process cell
- Intergrated with Boeing production systems
- 2 sided forming cell
- Transportable laser system

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# Palmdale, CA – laser peening for F-22

- Lockheed Martin Skunk Works
- Supporting F-22 upgrade program
- Advanced dual-gimbal beam scanning
- Floating pallet positioning system
- Transportable laser system

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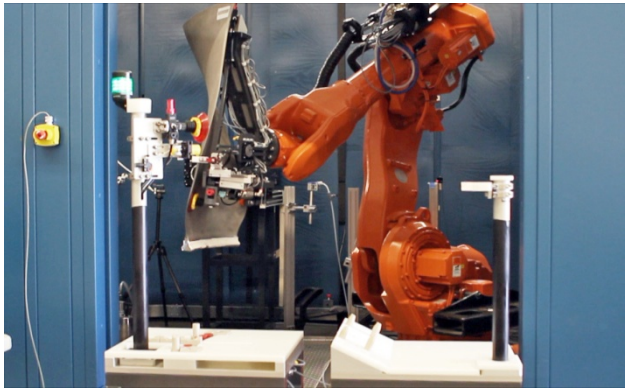
# Singapore – OEM aerospace blades

- Rolls Royce Seletar
- Supporting Wide Chord Fan Blade production
- Transportable laser system
- 2nd system installed in 2014

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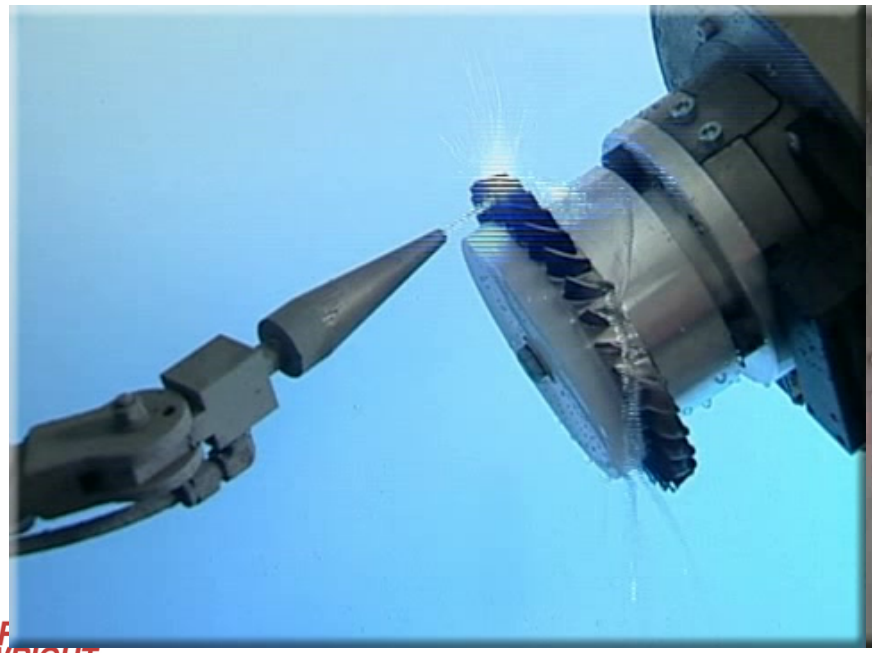
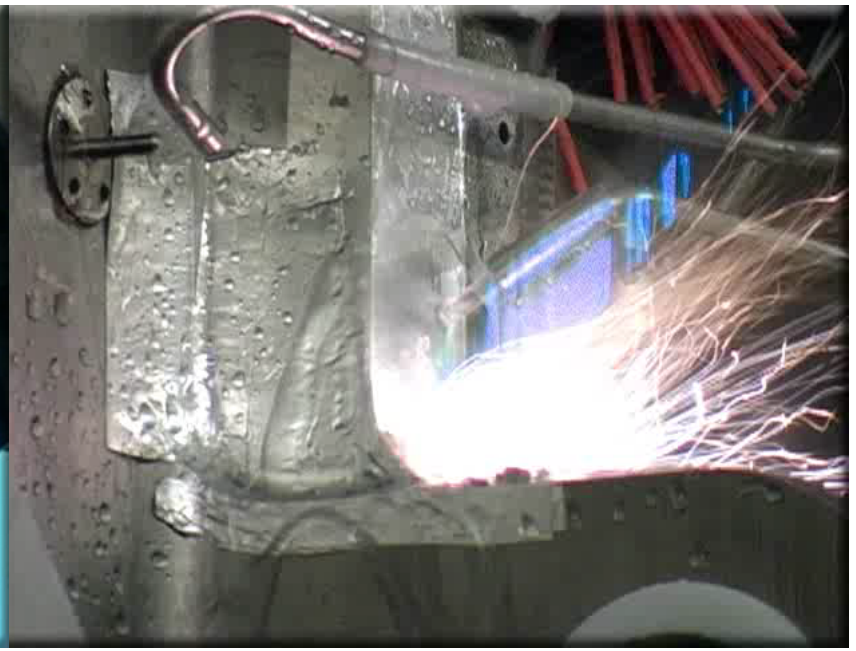
# Summary: Laser peening is ready for nuclear power applications

- MIC has developed advanced beam delivery which adapts laser peening to a wide range of customer products ranging in size from a small diesel fuel injector to a 100' long wing panel
- Successful implementation of a dual gimbal stinger specifically addresses the challenges of large component, on-site laser peening





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