# Image Cover Sheet

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**TITLE**

LASER PROCESSING OF NICKEL ALUMINUM BRONZE FOR USE IN PROPELLER FABRICATION AND REPAIR

**System Number:**

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# Laser Processing of Nickel Aluminum Bronze for Use in Propeller Fabrication and Repair

by

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## ABSTRACT

Laser beam materials processing technology was first employed on nickel aluminum bronze (NAB) cast components by the Applied Research Laboratory, The Pennsylvania State University (ARL Penn State) in 1989 to meet the stringent tolerance requirements of newly designed components and to provide a viable economic means of repairing existing damaged components. Laser beam welding (LBW) offers a low heat input process resulting in much less distortion of the workpiece as well as reduced residual stresses when compared to that observed in components welded using GMAW. Laser beam cladding (LBCL) is the process of melting alloying elements onto the surface of a metal to repair mechanically-induced structural damage and it can also be used to improve the wear and corrosion resistance of the base alloy.

Techniques have been developed for laser beam welding and cladding NAB cast and wrought materials using both high power carbon dioxide ($CO_2$) and neodymium yttrium aluminum garnet (Nd: YAG) laser systems respectively. The specifics of these techniques will be presented. Also, two approaches for LBCL NAB material onto NAB cast substrate have been developed by: i) melting NAB powder onto the substrate using a rather low power density rastering beam, and ii) melting NAB wire onto the substrate using a defocused high density beam. The resultant macro and microstructures of the two types of clads will also be presented.

# PRESENTATION OUTLINE

- Program Objectives (Original)
- Program Objectives (Redirected)
- Work Accomplished (through FY '95)
- Ongoing Work (FY '96)
- Future Plans

# PROGRAM OBJECTIVES
## (Original)

- Development of LBW processes and procedures for use on the SSN 21, SSN 688, and SSBN 726
  - minimize distortion of component
  - minimize residual stresses in component
  - reduce manufacturing costs
  - improve corrosion-resistance
  - improve cavitation-resistance
- Qualification of developed processes
- Transfer of technology to Navy facilities

# BENEFITS OF LASER MATERIALS PROCESSING ON PROPULSOR COMPONENTS

- Due to low heat input, starting and stopping minimized - continuous welding
- Parts can be welded in near final dimensions - machining costs reduced
- Less residual stress associated with laser welding process

# PROGRAM OBJECTIVES
## (Redirected FY '93)

- Development of laser-based repair and refurbishment processes and procedures for NAB components
  - LBW procedures
  - LBCL procedures
  - Development of processes using portable Nd:YAG
  - Robotic systems
- Qualification of developed processes
- Transfer of technology to Navy facilities

# WORK ACCOMPLISHED
## (through FY '95)

- Laser Beam Welding Procedures
- Laser Beam Cladding Procedures
- Thermocouple Studies
- Accelerated Corrosion Testing
- Long Term Corrosion Testing
- Cavitation Testing
- Fatigue Studies
- Tensile Test Results
- X-ray Residual Stress Analysis
- Microstructural Analysis

# WORK ACCOMPLISHED (cont.)
## (through FY '95)

Laser Beam Welding:

- Development of LBW techniques for NAB wrought plate and cast materials
  - 14 kW and 25 kW CO2 industrial lasers coupled to LARS units
  - thicknesses up to 5/8", with or w/out filler wire (e.g., 5/8" @ 23 kW, ~35 ipm)
  - LARS vision system/seam tracking for contoured surfaces

# WORK ACCOMPLISHED (cont.)
# (through FY '95)

Laser Beam Welding:

- Microstructural analysis of the metals meeting MIL 24480 has shown great variations in structure due to compositional fluctuations (w/in spec.) and thermal processing history
- Weld metal consists of proeutectoid $\alpha$ + martensite (same as that seen in conventional welds but on a much finer scale)
- Fatigue studies have shown that the laser welds fall w/in the same strength levels as the base metal casting while conventional welds were found to fail at significantly lower strength levels

# WORK ACCOMPLISHED (cont.)
## (through FY '95)

Laser Beam Welding:

- Long term corrosion tests have shown laser welds will perform at least as well as conventional welds
- Accelerated corrosion tests have shown that in the HAZ, martensite is anodic with respect to the surrounding $\alpha$ phase (less martensite is produced in laser welds when compared to that of conventional welds) and in areas adjacent to the base metal, $\alpha$ phase is anodic with respect to $\kappa_{iii}$ phase
- Ultra-high speed cavitation tests (in fresh water) have shown that the laser weld will perform at least as well as the base metal casting and conventional weld materials

# WORK ACCOMPLISHED
# (through FY '95)

## Laser Beam Cladding:

- Developed 3 techniques for laser beam cladding NAB onto NAB
  - rastering laser beam with powder deposit
  - nonrastering laser beam with powder deposit
  - nonrastering laser beam with wire deposit
- Each technique has unique advantages
  - maximum deposition rate = rastering beam w/powder
  - out-of-position cladding = nonrastering beam w/wire
- Each technique produces unique microstructures
  - rastering beam w/powder = primarily proeutectoid $\alpha$ (relatively soft, corrosion-resistant)
  - nonrastering beam w/wire = martensite + proeutectoid $\alpha$ (harder, wear-resistant)

# WORK ACCOMPLISHED (cont.) (through FY '95)

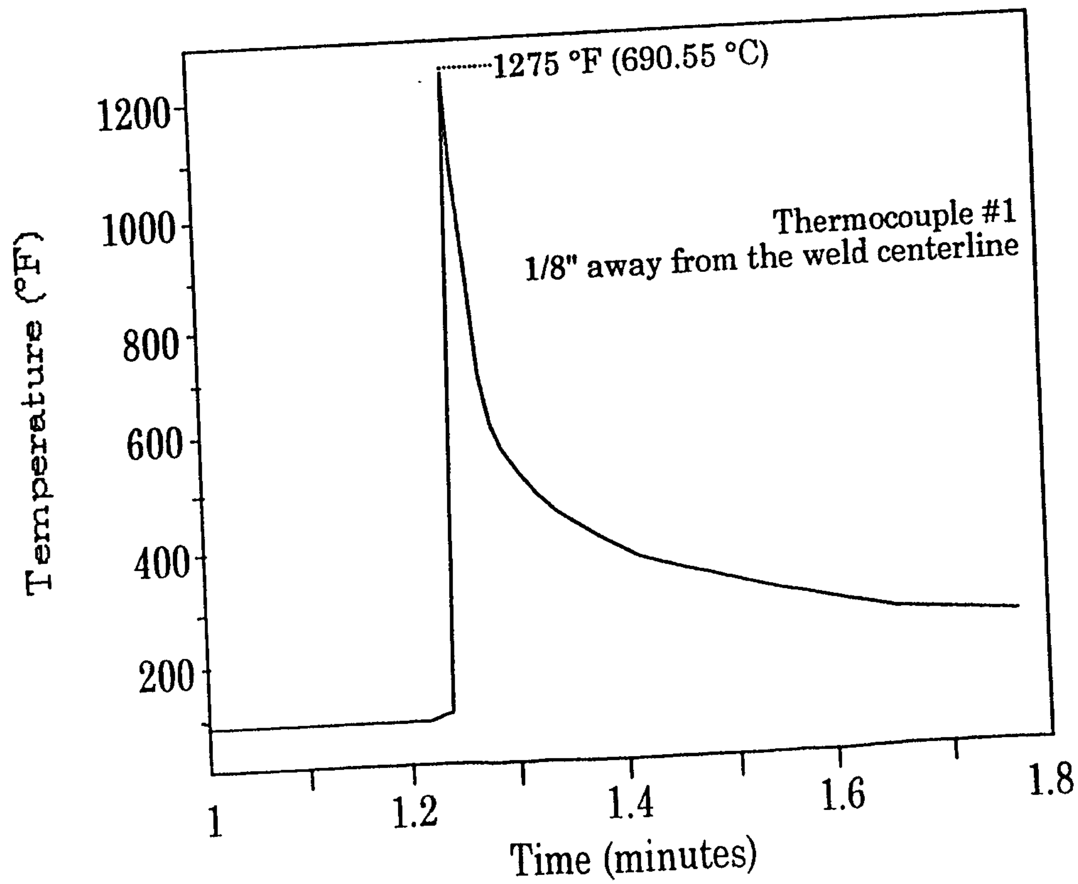
## Laser Beam Cladding:

- Thermocouple studies indicate a maximum temperature at the fusion line of 1331 °C and a preheat of ~80 °C between passes when cladding using a nonrastering beam w/wire deposit
- Dilatometry and DTA analyses have been used to better determine the melting and solidification temperature ranges of the base metal and the temperature ranges where critical phase transitions occur
- Ultra-high speed cavitation tests indicate that the laser beam clad (rastering beam w/powder) will perform at least as well as the base metal casting

# WORK ACCOMPLISHED
# (through FY '95)

## Thermocouple Studies:

Peak Temperature and Cooling Rate



# WORK ACCOMPLISHED
# (through FY '95)

## Corrosion Studies:

- Long Term Testing (300+ Days)
  - NRL Key West Facility
  - Flowing Sea Water
  - Base, LBW, MIG Welds Tested
  - LBW's will behave at least as well as the conventional welds
- Accelerated Testing
  - Two Methods
    - > weight loss
    - > electrochemical
  - Two HAZ areas susceptible to corrosion but less HAZ area in LBW when compared to conventional weld

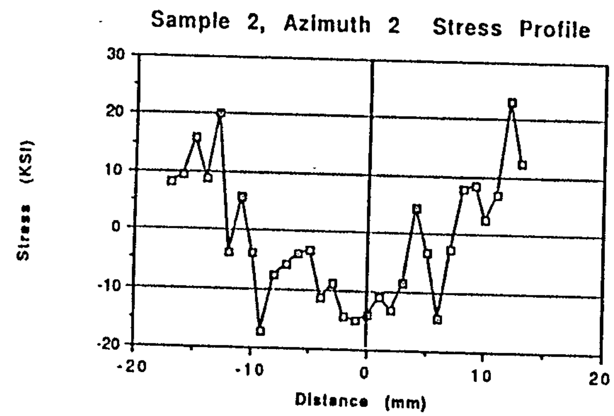
# WORK ACCOMPLISHED
## (through FY '95)

Cavitation Studies:

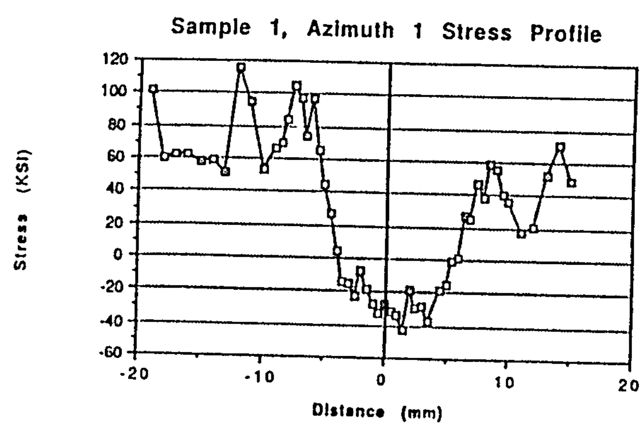
- Fresh Water
  - ARL Penn State Ultra-High Speed Water Tunnel
  - Base, LBW, MIG Welds, and LBCL
  - Laser Beam Processed NAB Behaved at Least as Well as the Base Metal
- Salt Water
  - Water Jet Hammer (ASTM G32)
  - Cavitation Erosion
  - Base and Laser Processed NAB
  - Laser Beam Processed NAB Behaved at Least as Well as the Base Metal Casting

# WORK ACCOMPLISHED
## (through FY '95)

## X-ray Residual Stress Analysis:




**Conventional Arc Weld**




**Laser Weld**

- Transverse scans across laser and arc weldments
- Both laser and arc welds were in compressive stress states
- Machining stresses were detected
- Laser welded material experiencing residual stress was 1/2 the volume of that seen in arc weldments

# WORK ACCOMPLISHED
## (through FY '95)

Tensile Test Results:

- Tensile Testing
  - Base metal casting = 55.7 ksi ys
  - LBW ~ 66.4 ksi ts, ~34.3 ksi ys
- Microhardness
  - Base metal casting ~ 150 VHN
  - LB Processes (wire) ~ 260 VHN
  - LB Processed (powder) ~ 170 VHN

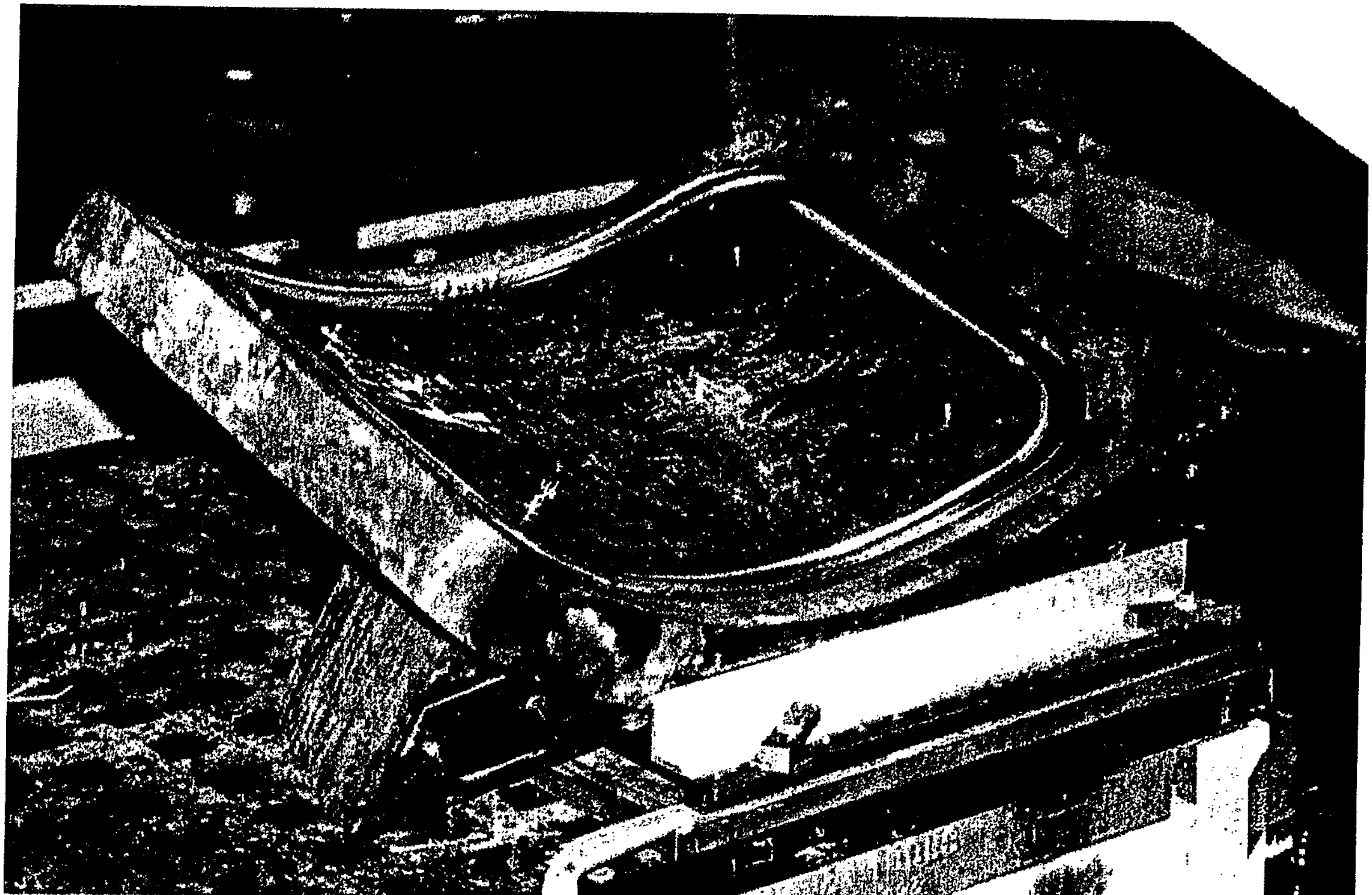
# WORK ACCOMPLISHED
# (FY '96)

- Welding procedures and joint configurations have been demonstrated that include autogenous and filler-added LBW of as-cast to as-cast and as-cast to wrought NAB in joint thicknesses up to 5/8" with join gaps up to 1/8"
- LBCL processes and procedures have been developed for depositing Inconel 625 onto NAB and for NAB deposited onto steel substrates
- LBCL processes and procedures have been developed for depositing NAB onto Al alloys (shear strengths ~ 22 ksi, NAB on NAB shear strengths ~28 to 30 ksi)
- LBW Distortion Measurements (NSWC)
  - Mock "conventional" joints compared to conventional welding processes
  - LBW distortion ~0.094" in the longitudinal direction, less than any other welding process
  - Mock "laser" joints produced ~0.031" longitudinal distortion, significantly less than any other welding process

# WORK ACCOMPLISHED
# (FY '96)

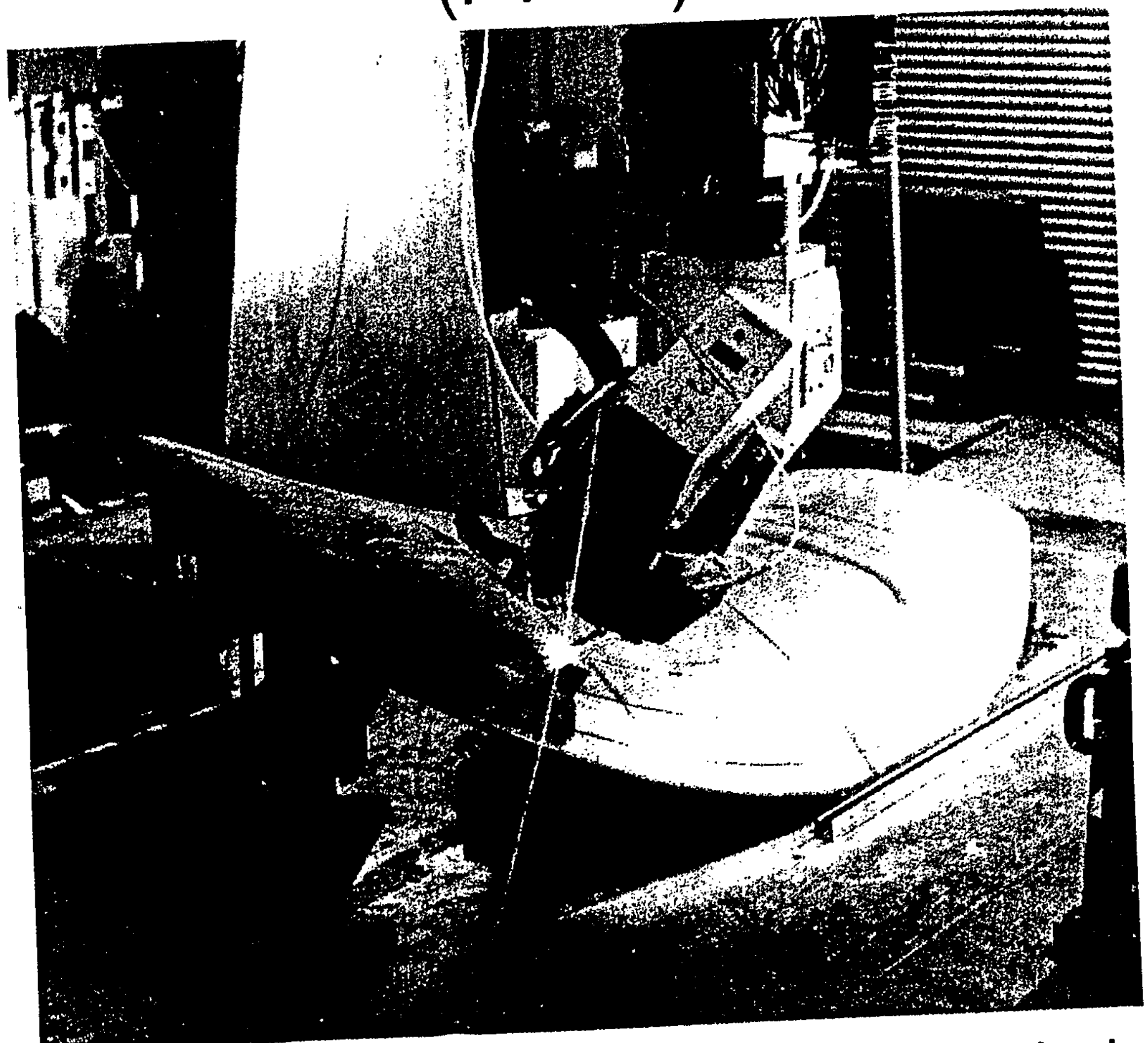
- LBW was included in the fabrication of the LSV
- Laser beam welds can be made within 1/8" of temperature-sensitive material (adhered to 3/8" thick NAB) without degradation of the material or the adhesive (3 different adhesives were tested)
- The 3c demo piece was LBW for NSWC using the LARS
- A full scale 688 blade was seam tracked and laser welded using the LARS
- ARL Penn State was awarded a Laser Line Bending Program by ARPA with Rocketdyne, Newport News, Ingalls, Boeing, and MIT for forming complex shapes using differential laser heating techniques
  - "Dishing" of 0.25" thick NAB wrought plate has been demonstrated

# WORK ACCOMPLISHED (FY '96)



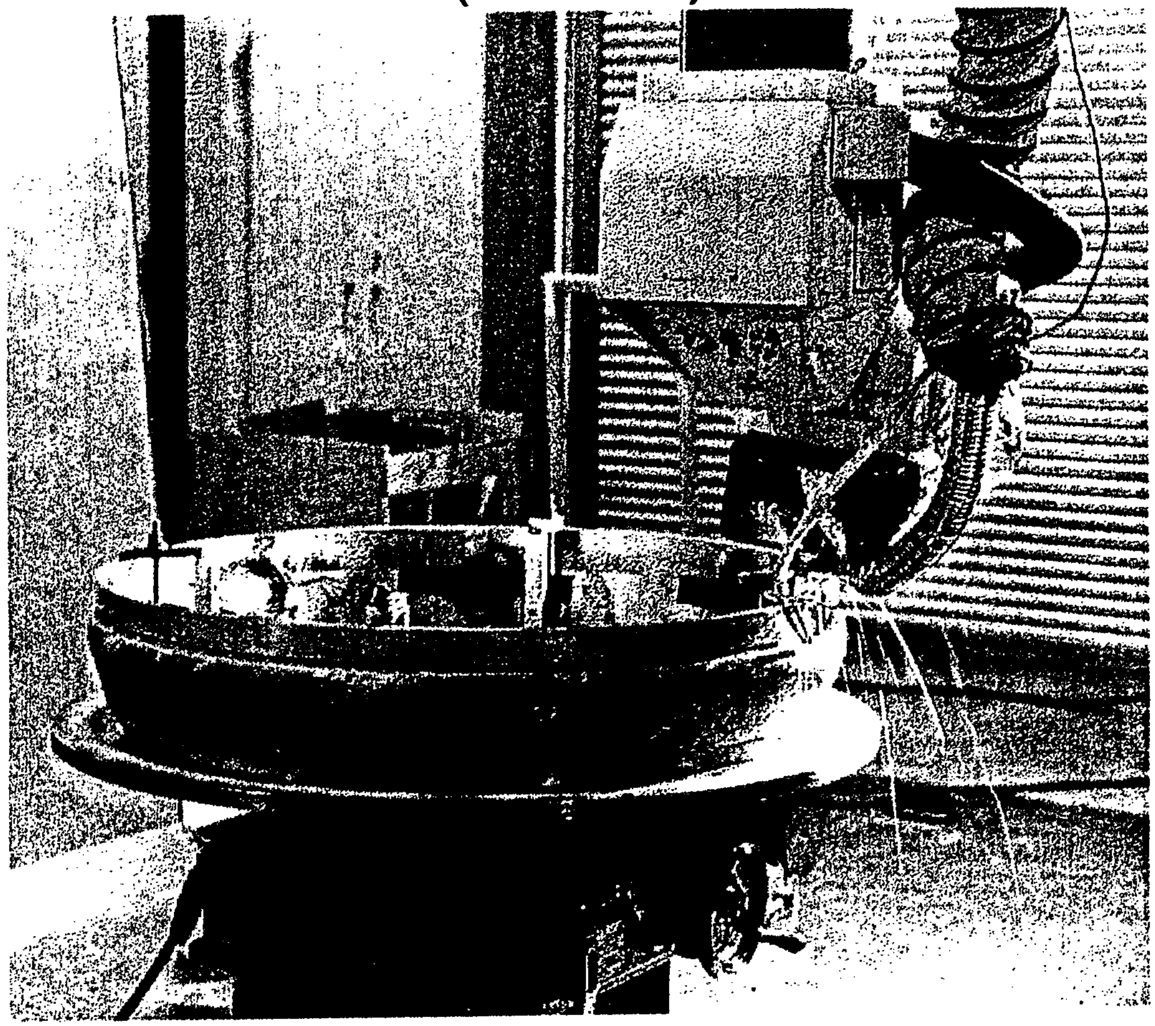
Laser beam welded mock joint for NSWC, seam tracked using LARS

# WORK ACCOMPLISHED
# (FY '96)



Laser beam welded SSN 688 blade, seam tracked using LARS

# WORK ACCOMPLISHED
# (FY '96)



Laser beam welded circular component for LSV, welded using LARS

# FUTURE PLANS

- Qualify LBW processes using the LARS and CE 25 kW $CO_2$ Systems
- Qualify LBCL processes using the LARS and CE 25 kW $CO_2$ Systems
- Qualify LBW processes using the Hobart 3 kW Nd:YAG System (at 2.4 kW power levels)
- Qualify LBCL processes using the Hobart 3 kW Nd:YAG System (at 2.4 kW power levels)
- Write NAB Technical Reports