Cobots in Ship Manufacturing, High Mobility Manufacturing Robot, Integration Opportunities

March, 2023

NSRP RA Project TIA #2020-303

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Overview

- Robots / Cobots in manufacturing
- Multi-function shipbuilding robot – Mantech project update
- Sample Applications
- Review the NSRP RA Project TIA #2020-303
- Technology transitions to Miller Copilot
- Future integration opportunities of cobots in ship manufacturing

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Multi-Function Shipbuilding Robot

ManTech Project No. S2904

Center for Naval Metalworking (CNM)

Contract 2017-508, Task Order 007

Period of Performance: April 2021 – January 2025

Project Team

Neil Graf – ManTech Director
Jeff Farren – Program Officer

Mark Snider – Director
Paul Blomquist – Sr. Technical Advisor
Jeremy Brougher – Technical Director
Dan Meath – Project Manager

Lee Fuglestad – PMS 400D4
CDR Lennard Cannon – PMS 400D4
David Clark – CACI

John McGrorey – TWH 05P24
James Thomas – NSWCCCD TA
Chris Harkins – NSWCCD TA

Christen Leggett – Project Manager
Gary Rosetti – Technical Lead
Ambre Cauley – ManTech Program Manger

[ONR Contract Modification In-Process]

Issue Description

- Current welding processes for vertical and horizontal erection joints are performed either manually or using a mechanized system which uses a track for a welding tractor to ride on.
- Installing this track for a single weld seam becomes cumbersome with the use of multiple sections of track, subsequent measuring to ensure proper placement of track in relation to the weld seam, and the additional process of tacking the track in place.
- All of these tasks are performed using either scaffolding or man lifts, increasing manufacturing costs.

Project Objectives / Approach

- Develop a prototype for a trackless crawler with the capability to weld horizontal and vertical erection joints.
- Develop the foundation for the surface preparation, inter-pass cleaning and inspection of the weld joints.

The multi-function robot system will be developed using a phase based approach where each iterative phase builds upon the foundation of the previous phase(s):

- Phase 1 - establish requirements for each of the desired processes and research the currently available technologies
- **Phase 2 - implement the automated robotic welding processes**
- Phase 3 - develop surface preparation capability
- Phase 4 - develop capability of in-process and/or final inspection

This project only funds the initial two phases.

Project Goals

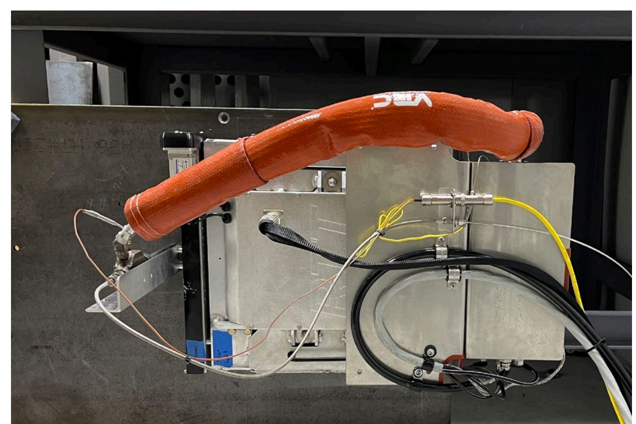
- **Goal 1**: Reduce labor hours required to erect scaffolding and track welding set up
  - Man-lifts and craft support may still be required for the initial set-up of the robotic system and the final inspection procedures. However, reduction of the required scaffolding will provide significant labor savings.
- **Goal 2**: Decrease labor hours needed to weld erection joints by 50%
  - While the weld parameters / weld speed is not expected to change, the "arc on-time" for the weld process will be increased.
- **Goal 3**: Decrease hours needed to rework and re-inspect welds by 50%
  - The increased weld quality provided by a mechanized welding process will result in reduction of rework and the resulting re-inspection.

Innovation and Impact

- Commercial off the shelf (COTS) solutions exist for trackless welding, vision systems, remote welding software, laser tracking, path planning software, and remote inspection methods. However each of these are currently stand-alone processes.

- This project will each of these capabilities into a single, stand-alone automated system.

- This project will also implement repeatable and predicable processes for each of the desired capabilities, resulting in increase efficiency and higher end product quality.



Cobot: A definition

- Cobot – Collaborative robot
- Robot intended for direct human interaction with shared space or proximity (IFR)
  - Traditional robotics – separate robots from human contact during operation (safety)
  - Cobots – achieve safety through weight, materials, geometry, sensing, controls
- Recent development (1997 patent) stemming from GM robotics center and University research

Four Levels of Collaboration between worker and cobot (IFR)		
Coexistence	Work side by side (no protective barrier)	
Sequential Collaboration	Share the workspace	
Cooperation	Work on the same part, at the same time	
Responsive Collaboration	Cobot responds to worker	

Cobot companies - timeline

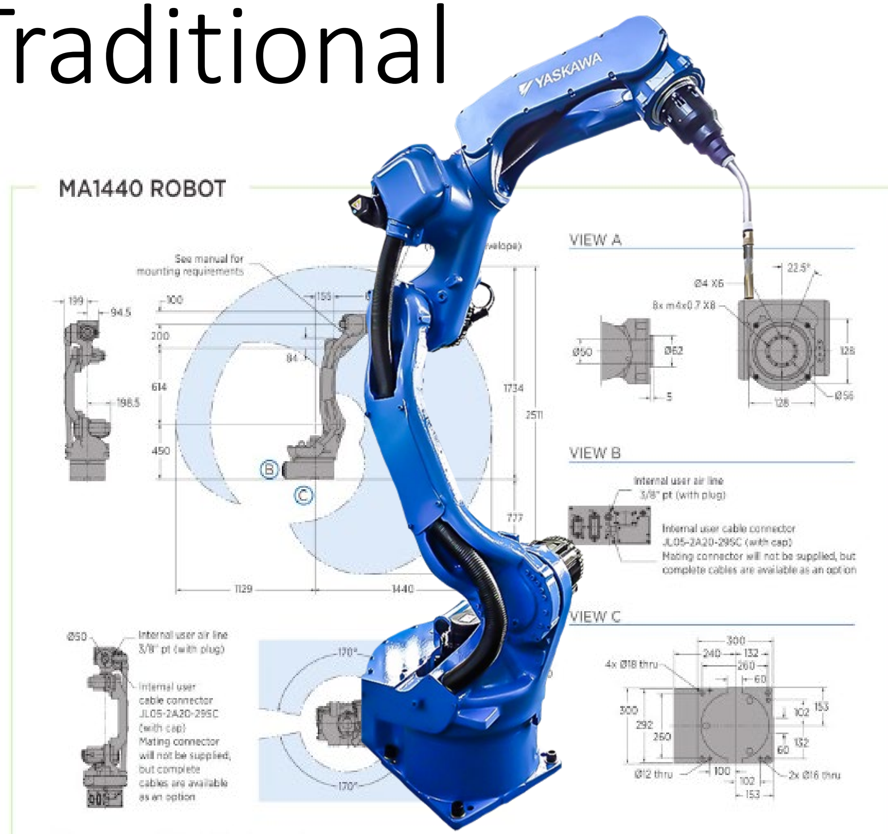
- Cobotics (late 1990's) - Automotive assembly
- Kuka cobot – 2004 (LBR series)
- Universal Robotics (2008)
- Rethink Robotics – (2011) Baxter
- Yasakawa (Motoman, 2013)
- AUBO robotics (2014, Smokie Robotics)
- FANUC (2015) CR series
- ABB (2015) YuMi
- Welding Examples
    - Fabtech 2018 – 2 welding cobots
    - Fabtech 2023 - 20+?

Comparing robot specifications: Collaborative Vs. Traditional

UR10 Technical specifications Item no. 110110

6-axis robot arm with a working radius of 1300 mm / 51.2 in

Weight:	28.9 kg / 63.7 lbs
Payload:	10 kg / 22 lbs
Reach:	1300 mm / 51.2 in
Joint ranges:	+/- 360°
Speed:	Base and Shoulder: 120°/s. Elbow, Wrist 1, Wrist 2, Wrist 3: 180°/s. Tool: Typical 1 m/s. / 39.4 in/s.
Repeatability:	+/- 0.1 mm / +/- 0.0039 in (4 mils)
Footprint:	Ø190 mm / 7.5 in
Degrees of freedom:	6 rotating joints
Control box size (WxHxD):	475 mm x 423 mm x 268 mm / 18.7 x 16.7 x 10.6 in



All dimensions are metric (mm) and for reference only.
Request detailed drawings for all design/engineering requirements.

SPECIFICATIONS

Axes	Maximum motion range [°]	Maximum speed [°/sec.]	Allowable moment [N•m]	Allowable moment of inertia [kg•m²]		
S	±170	230	-	-	Controlled axes	6
L	+155/-90	200	-	-	Maximum payload [kg]	6
U	+240/-175	230	-	-	Repeatability [mm]	±0.08
R	±150	430	10.5	0.28	Horizontal reach [mm]	1,440
B	+90/-135	430	10.5	0.28	Vertical reach [mm]	2,511
T	±210	630	3.2	0.06	Temperature [°C]	0 to +45
					Humidity [%]	20 - 80
					Weight [kg]	130
					Power rating [kVA]	1.5
					Internal I/O cable (feeder control)	18 conductors
					Internal gas line	(1) 3/8" connection

- Similar payload and reach, 29 vs. 130kg arm mass

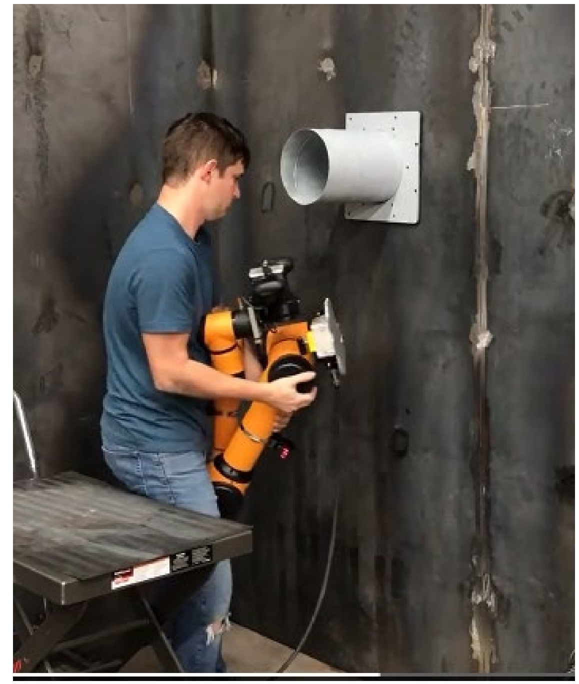
Cobot Theory, Standards and guidelines

- ISO 10218-1/2:2011 Safety Requirements for Industrial Robots
- ISO/TS 15066:2016 Robots and robotics devices – Collaborative robots
- Subject to Quasi-static and transient effects
- Bounds on mass, speed control, and torque sensing

- Operational impacts on cobot design
  - Weight/mass
  - Speed
  - Accuracy
  - Stiffness
  - Exterior shell

RTT- based cobot applications:

- HMMR (Cobot on mobile platform
- Portable cobot systems
- Integration with track/positioners



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NSRP RA Project TIA #2020-303 Review

1) Increase the range of opportunities for mechanized welding through a lightweight, portable (or mobile) robot
2) First, apply to general fillet weld types
    1) 2F (Horizontal)
    2) 3F (Vertical)
    3) 4F (Overhead)
3) Second, apply to specific jobs (welds joining stiffeners to deckplate, bulkhead intersections)

Motivating problem:

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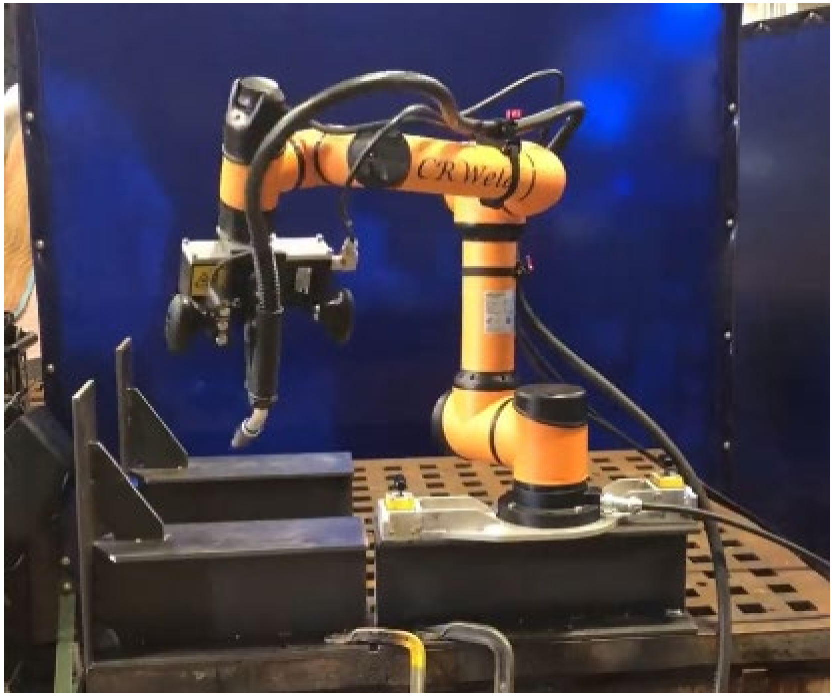
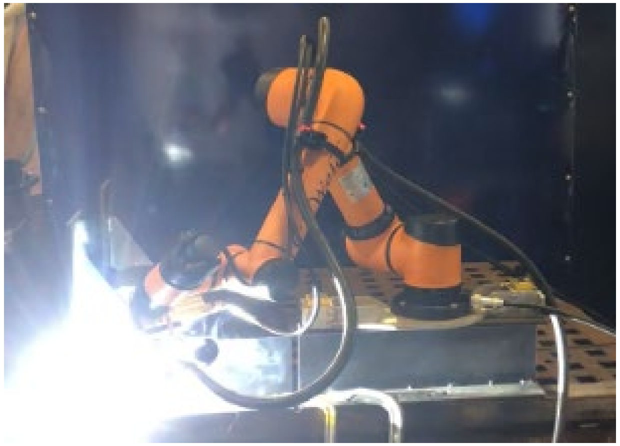
Overview of Proposed System

1) Operator places HMMR on stiffener and switches mag-locks
2) Robot scans and welds stiffener and gusset on either side
3) Operator releases mag-locks, slides HMMR to the next stiffener
4) Repeat





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Develop Platform Hardware (HMMR-lite)

- Base: Magnetic switchable
- Arm: commercial cobot
- End-effector: Supports torch and user interface
- Algorithms: Control robot motion, path, and job planning
- System is man portable (approx. 50 lb)

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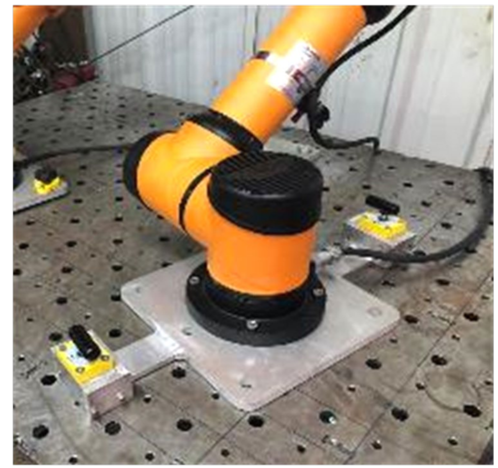
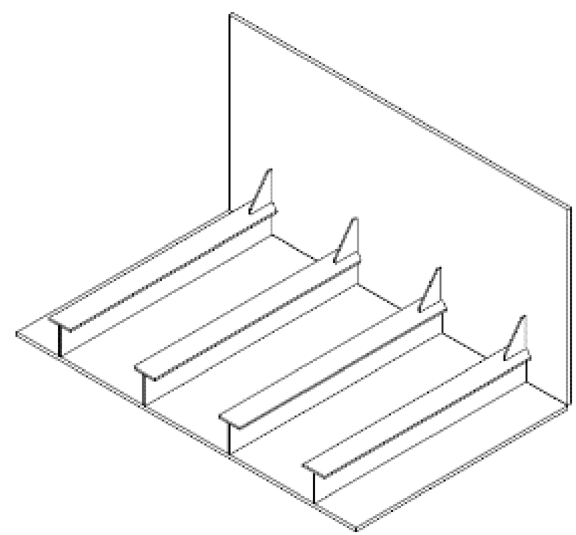
Mobility Requirements

- Task: T-stiffeners with fillet welds at deckplates and bulkheads
- Task workspace: ~300 mm (12 in) sphere
- HMMR workspace: ~ 950 mm (37 in) sphere
- HMMR positioned on stiffener





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Demonstration of HMMR Hardware

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Algorithm and Controls Development

- Path planning is performed by the robot
- Robot maps the workspace
  - Develops high-level path guide
- Scans weld seams
  - Builds model of weld seam and develop accurate weld path
  - Integrates the weld schedules according job requirements
- Scanning tools
  - Lidar
  - Structured light vision

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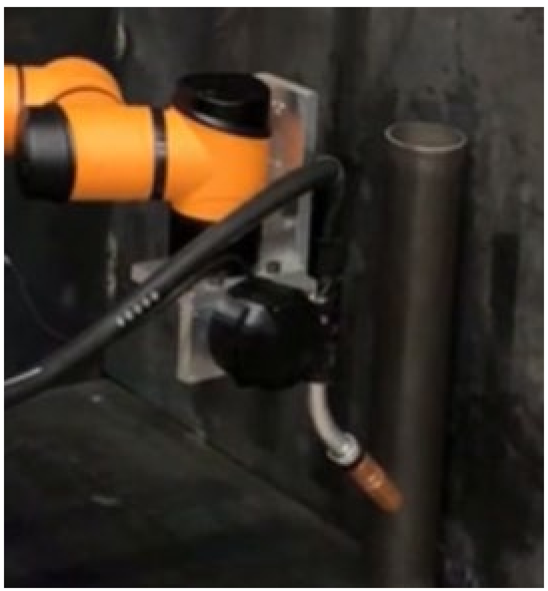
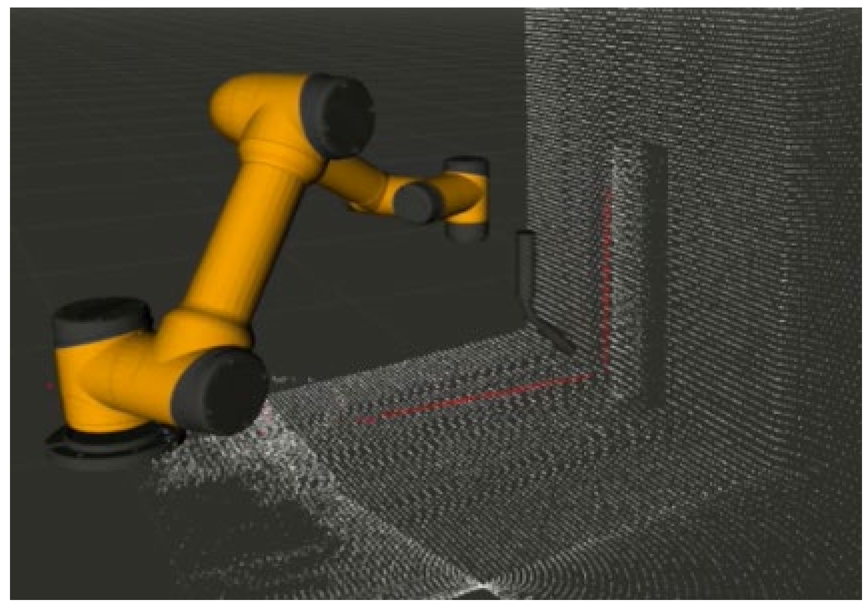
Scanning Tool – Lidar

- Scanning Lidar
  - Generate point cloud
  - Use to find key features
  - Detect objects





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Development of Open/Closed Loop Welding

- Weld power source communication
  - HMMR controller communicates with power source and wire feeder through Miller's cobot adapter
  - Interface for cobot control of large range of Miller power supplies
  - Works with popular S-74 MPa wire feeder
  - Provides full control over voltage/wire speed and process settings
  - Path planning includes selecting proper weld schedule – pull from selected set of validated weld schedules

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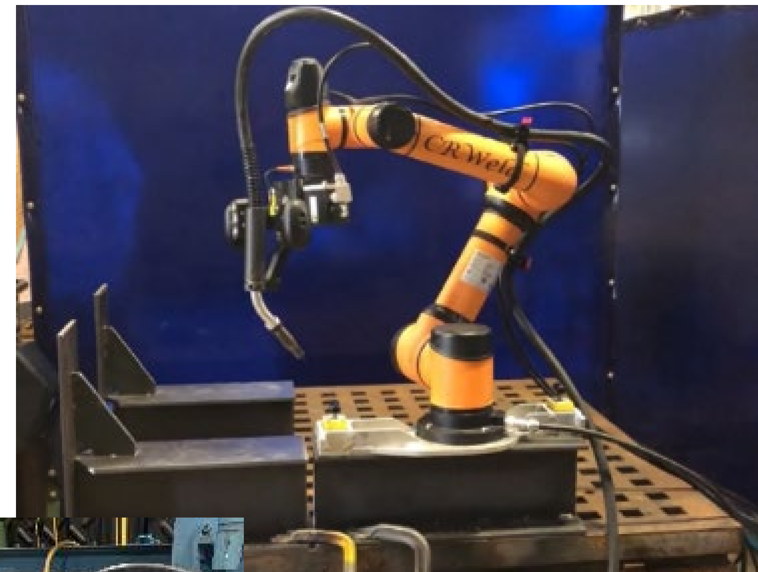
HMMR Prototype Ready for Testing on Selected Joints

- HMMR arm with portable base attached to stiffener
- Control system configured with integrated welder control (Miller Invision 352 MPa shown here)



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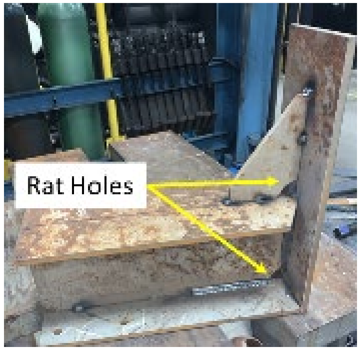
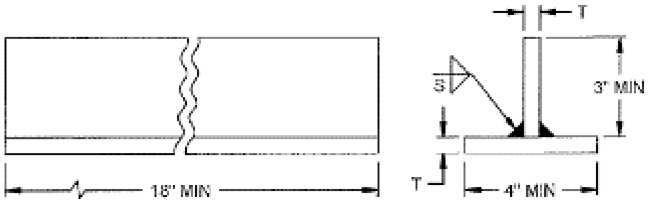
Overview of Welding Process Development and Evaluation



- Procedures were developed to meet requirements of Tech Pub 248 Rev. 1
- Base materials: 5/16 in and 3/8 in thick primer coated DH36 steel
- Wire: MIL-71T-1
- Shielding gas: 100% CO_2
- Gap tolerance: 0 to 1/16 in
- Minimum leg size: 1/4 in
- 2F, 3F, 4F procedures developed and evaluated

S9074-AQ-GIB-010/248 Rev 1



T = MAXIMUM THICKNESS TO BE USED IN PRODUCTION OR 3/8 INCH, WHICHEVER IS THE LESSER.

S = MAXIMUM SIZE SINGLE PASS FILLET TO BE USED IN PRODUCTION.

NOTES:
1. Plating shall be either ordinary or higher strength steel, as specified in MIL-S-22698, which qualifies the procedure for use on these materials.
2. Plating shall be primer-coated to maximize thickness that will be applied in production.
3. Plate shall be welded in the horizontal position and shall qualify for all positions.
4. Remove first side weld by gouging or mechanical means and fracture second side weld. Test assembly may be cut into shorter lengths after welding to facilitate fracturing for examination.

Figure 7-9. Procedure Qualification Test Assembly for Fillet Welding Over Primer-Coated Surfaces

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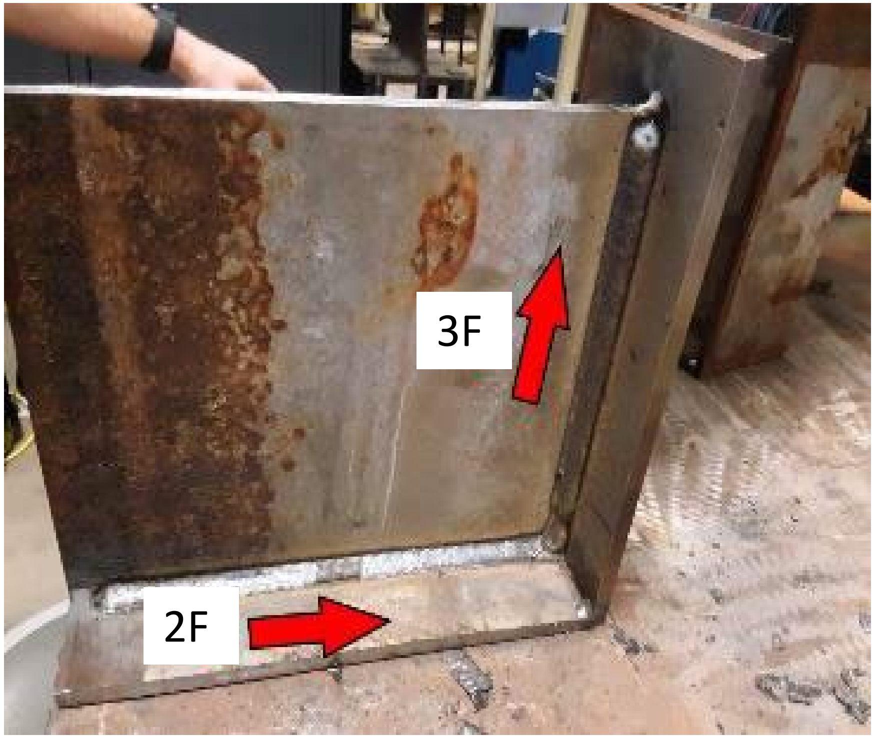
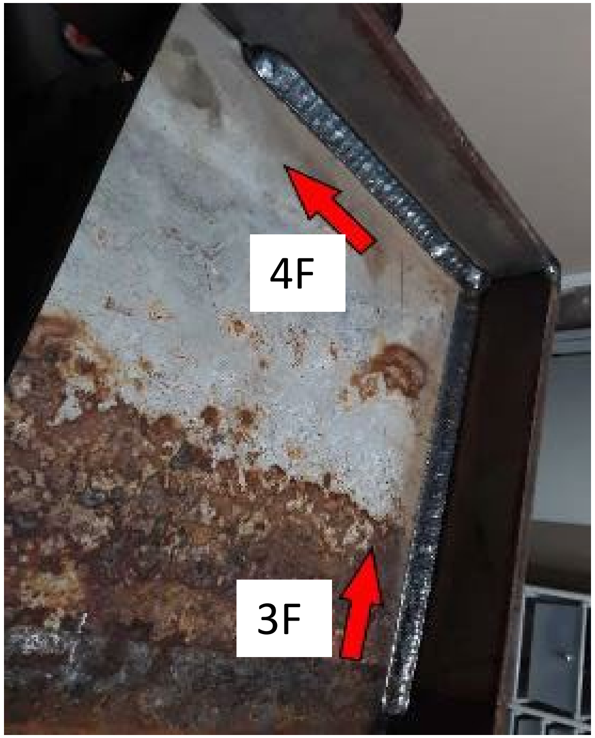
Procedure Implementation

Step 1: General Fillets

- Develop procedures to create acceptable tie-in and weld profile between welding positions





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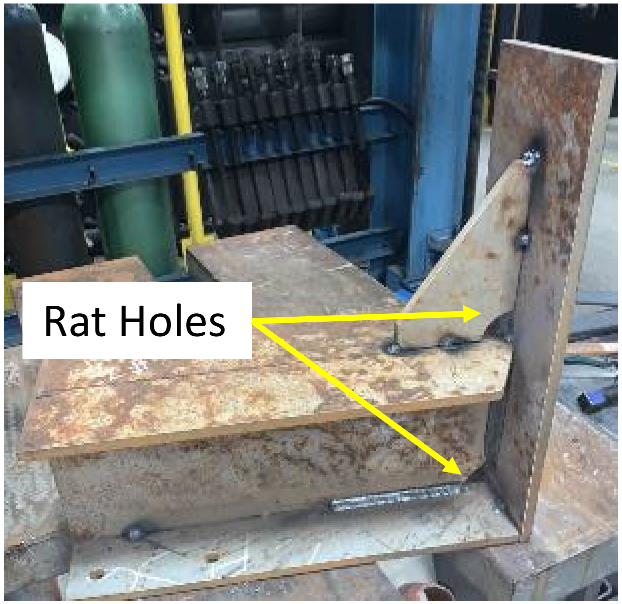
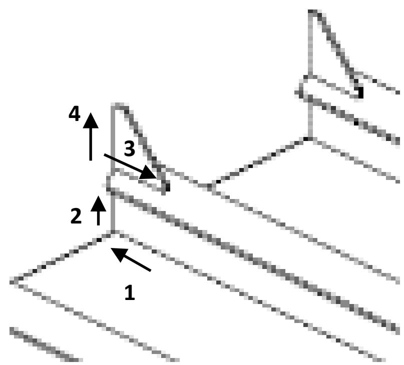
Procedure Implementation: Welding on Bulkhead Mockups





- Welding on the bulkhead mockups requires development of wrap procedures
- Accessibility considerations prove challenging to complete full wraps with acceptable tie-in and weld profile

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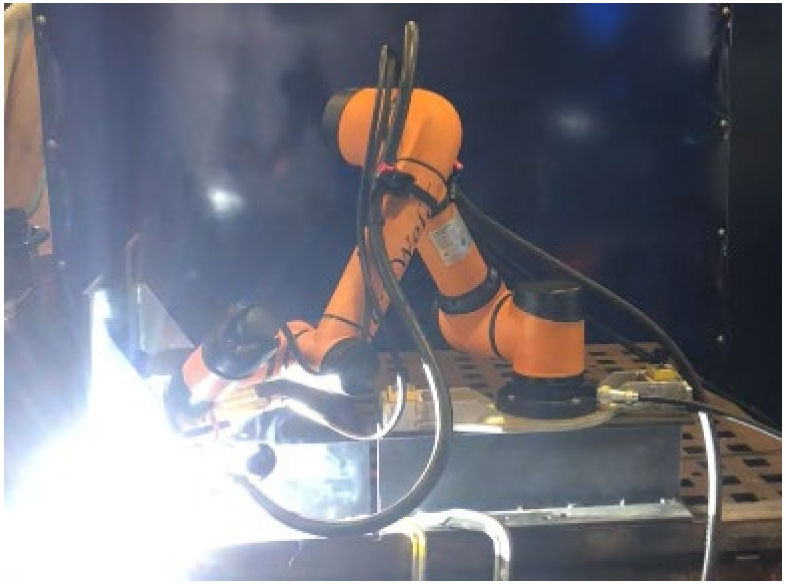
Testing

- Process development
- Qualification
- Time studies
- Reliability



Testing location	Primary purpose	Operation time* (hrs)	Scan time** (hrs)	Weld time** (hrs)	Other** (hrs)
RTT	Motion control development	75	19	37	19
EWI	Weld process development	20	3	4	13
Vigor	Process qualification, training, evaluation	16	2.4	5	8.6
Total		111	24.4	46	40.6

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Testing at Vigor

- Spring, 2022
- Weld Qualifications
- Training
- Replicated systems

No Distribution

Qualification procedures

Page 1 of 2

VIGOR

WPS# VI 2F, 3F, 4F Positions

Robotic Automatic Flux Cored Arc Welding (FCAW)
100% Co2

Welding Procedure Specification (WPS)

S1 to S1 Carbon Steel

Written By: Kenneth Johnson **Approved By:**

Revision No. 0 **Date:** 4-Mar-22 Vigor Industrial Quality Assurance

NAVSEA APPROVAL

Substantiating PQR: VI **Dated:** **SUPSHIP Puget Sound :**
Substantiating PQR: VI **Dated:** **NAVSEA Approval :**

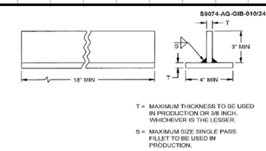
JOINTS

Qualified within the limits of the joint design in MIL-STD-22.
Robot: HMMR-lite Software: RTT Space Mapping (SSM1.0)
Scanner: Gocator 2340

BASE METAL

MATERIAL SPEC :	MIL-22698
TYPE OR GRADE :	ABS A36
THICKNESS OF TEST COUPON :	1/2"
Diameter	N/A
Coating:	NiPi Interplate 997

Method of Application:
Airless spray, Brush, Conventional Spray, Roller



FILLER METALS

SPECIFICATION :	AWS A5.20
FILLER TYPE :	E71T1
SIZE / BRAND OF FILLER :	.045 ESAB
Clad/HF Thickness/Layers	N/A
MATERIAL LOT # :	,100711
SIZE / BRAND OF FILLER :	0.045 ESAB
MATERIAL DATE :	2/28/2022
MATERIAL LOT # :	,10071
MATERIAL LOT # :	MIL-71T-1-HYC

JOINT PREPARATION

BEVEL : Machined, Saw Cut, or Ground
CLEANING : The surface to be welded and adjacent base material for a minimum of 4 inches shall be free of oil and grease.

GAS

	Gas	Mixture	Flow Rate CFH
Shielding	CO2	100% CO2	30-45 CFH

TORCH, TUNGSTEN, & GAS CUP

TUNGSTEN ELECTRODE SIZE :	N/A
TUNGSTEN ELECTRODE TYPE :	N/A
ELECTRODE EXTENSION :	N/A
TORCH TYPE :	NA
GAS CUP SIZE :	5/8" I.D. & 3/4" I.D.

Automatic Torch Position:
Work Angle to Web: 2F: 40°,3F: 45°,4F: 45°
Wire Feed Angle: 2F: 5° push, 3F: 5° drag, 4F: 5° drag

ELECTRICAL CHARACTERISTICS

CURRENT : DC(EP)
POLARITY : Reverse
POWER SUPPLY : Miller AlumaPower 350 Mpa or similar
WFS S-74 MPa Plus or similar

Actual Values	2F	3F	4F
Wire Feed Speed	415	265	375
Voltage	29	25	27
Travel Speed	14.1	6.1	11

Welding Progression: 2F (Horizontal), 3F (Vertical Up), 4F (Overhead)

TORCH TYPE

Tergaskiss CA3 Robotic Air-Cooled MIG Gun

GAS CUP SIZE

Taper Nozzle size shall be 5/8" to 3/4" I.D.

Weaving Parameter Weave Amplitude (in.): 2F: 0.15, 3F: 0.13, 4F: 0.20
Weave Frequency (Hz.): 2F: 4.5, 3F: 2.0, 4F: 3.0 Dwell Time (sec.): Right: 0.4, Left: 0.4

Page 2 of 2

VIGOR
Welding Procedure Specification (WPS)

WPS# VI 2F, 3F, 4F Positions

THICKNESS RANGE QUALIFIED

S9074-AQGIB-010/248 rev 1 Table (7-6)

Plate Range: Groove Joint - N/A Fillet Joint - 0.5" to Unlimited
Pipe Range: Groove Joint - N/A Pipe Fillet Joint - N/A

PREHEAT AND INTERPASS

Preheat shall be 60°F minimum and Interpass shall not exceed 150°F maximum. 110°F is considered optimal. Temperature measurement shall be made prior to welding and between passes. Surface contact pyrometers or other suitable devices shall be used. Temperature Indicating Crayons SHALL NOT be
Preheat: Ambient PWHT: N/A

GAS

	Gas	Mixture	Flow Rate CFH
Shielding	CO2	100% CO2	30-45
Backing	N/A		

ELECTRICAL CHARACTERISTICS

Current: DC (EP) **Polarity:** Reverse GMAW DC Pulse
AMP (Range): 265-415 **Volt (Range):** 25-29
Welding current ranges specified are recommendations only. Actual current will vary depending on filler brand, craftsperson skill, joint design and position

NOTES:

1 Welder Qualification : Per NAVSEA Technical Manual S9074-AQ-GIB-010/248 Rev 1.

2 Edge Preparation : Plate edges may be prepared by cutting, machining, burring, sanding or filing. Oil SHALL NOT be used.

3 Weld Cleaning : The surface to be welded and adjacent base material for a minimum of 4" shall be free of oil, grease, and markings. Wire brushing with a handheld stainless steel wire brush, power driven stainless steel wire brush may be used with Caution not to smear the metal.The Stainless Wire Brush will have ONLY been used for CuNi. Carbide burring of the joint surface after cutting the joint has been found to be an effective means to remove smeared metal which trap contaminants. Clean all weld passes prior to depositing the next.

4 Pior to all welding all weld areas shall be wiped clean with Isopopanol 3, PG II or equivalent.

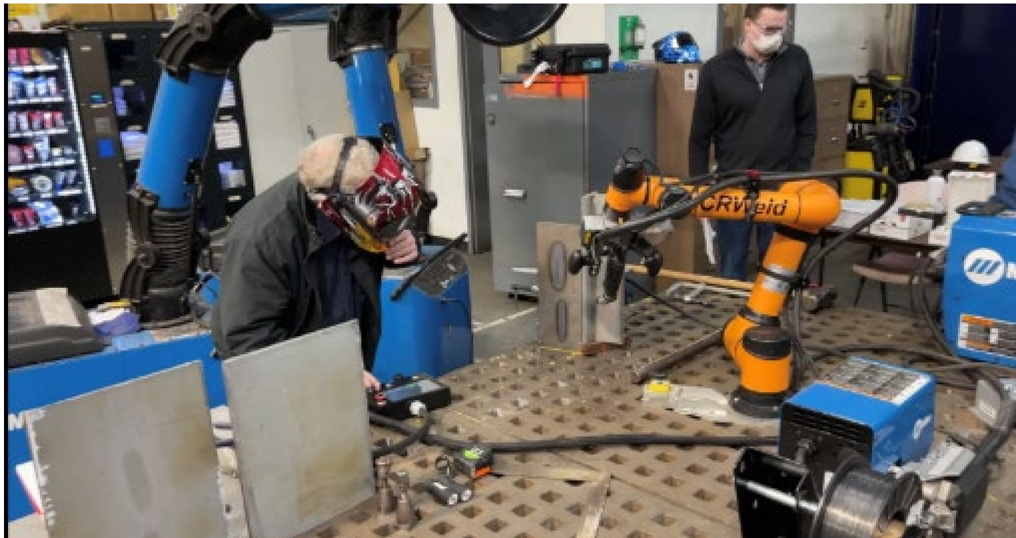
5 Weld Technique : A) Tack welds shall be small and appropriately placed to assure proper joint Fit-Up.
B) Weave Bead Method may be used with a maximum with of 1/2".
C) CTWD - Cup to work distances 1/2" Tip to work distance 3/4"

6 Weld Size : Shall be IAW applicable fabricating documents.

7 Inspection : Visual Inspection of final weld shall be required prior to any other subsequent inspections or Nondestructive Testing IAW Fabrication Documents.

8 Welding Requirements : Welding shall be accomplished IAW MIL-STD-1689A (Structural), and NAVSEA Tech Pub T9074-AR-GIB-010/278 (Machinery, Pipe & Pressure Vessels),

Training/Qualification/Testing



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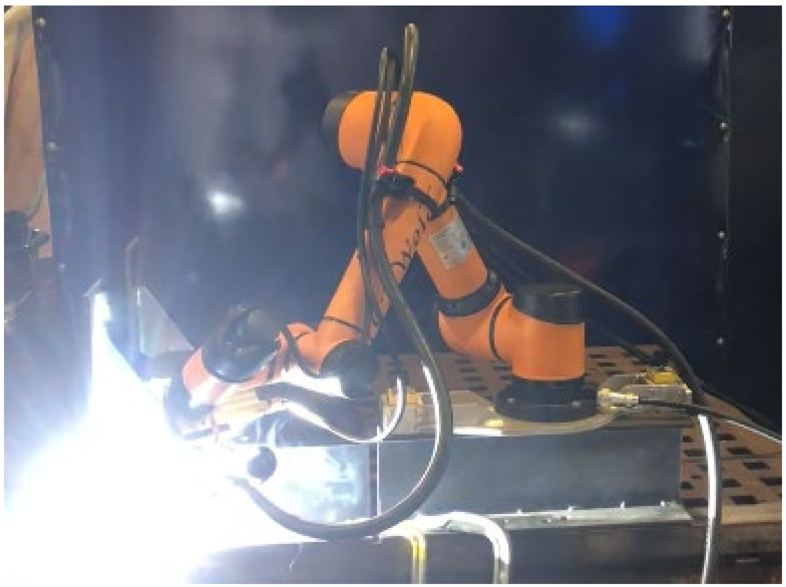
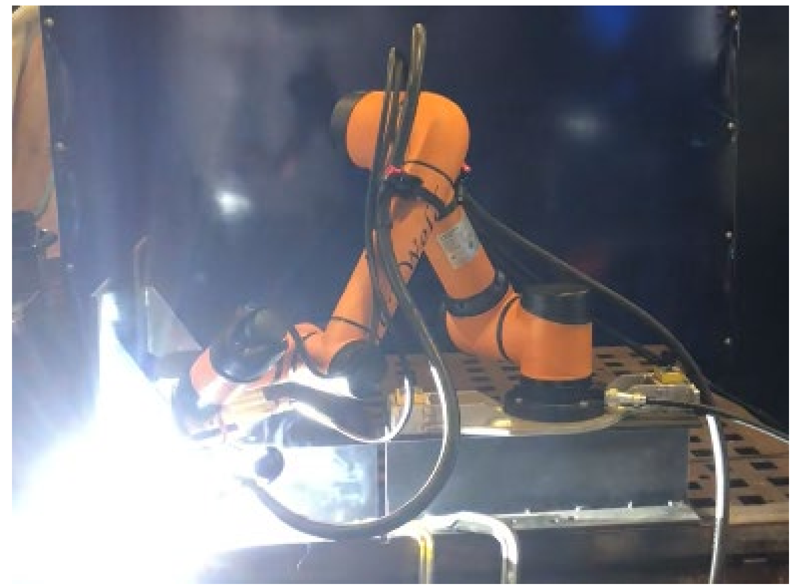
Testing

- Videos of operation





Complete scan and weld
https://vimeo.com/528391072/171c0faace

Welding of gusset
https://vimeo.com/528392166/d6e4eb581d

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Cost-Benefit Analysis

- Sub 8 min process time with robot, 80% efficiency
- 12X increase in Operator through-put
- Speed, reduced stress, high arc-on time

Welding Efficiency and rates			**Unit Costs**			
Manual welder's efficiency (arc on time)*	6%	ME	Manual Operator (Labor) Cost		$60.00	MOC
Automation (HMMR) Efficiency**	50%	RE	Robot-augmented operator cost		$87.90	ROC=MOC+C*RC
HMMR Robots serviced by one operator	3	#R	Cost per unit of weld, Manual		$133.33	CWM=MOC/UWM
Units of weld (Stiffener completed) per hour, Ma	0.45	UWM=ME*60min/hr	Cost per unit of weld, HMMR-augmented		$7.81	CWR=ROC/UWR
Units of weld (Stiffener completed) per hour, Operator augmented with 1 HMMR	3.75	UWR=RE*1*60min/8min weld				
Units of weld (Stiffener completed) per hour, Operator augmented with 2 HMMRs	7.5	UWR=RE*2*60min/8min weld				
Units of weld (Stiffener completed) per hour, Operator augmented with 3 HMMRs	11.25	UWR=RE*3*60min/8min weld	Savings per unit of weld		$125.52	S=CWM-CWR
Robot Hourly Cost			**Period Cost Savings**			
Initial Robot Cost	$ 50,000	RIC	Hours worked per shift years		1920	H
Initial Setup cost	$ 18,000	SUC	Total Units of weld - per augmented op. per year		7200	TU=H*UWR/#R
Maintenanc cost over life a % of purch price	50%	MC	Savings per augmented operator per year	$	903,744	SY=TU*SU
Life of Robot (hrs)	10000	LR	Total savings over implementation period	$	4,518,720	S=SY*R*Y
Robot Hourly cost	9.3	RC=(RIC*(1+MC)+SUC)/LR				
Implementation period			**ROI Calculations**			
Robots implemented (#)	3	R	Proposal cost (Includes 1 robots)	$	500,000	
Implementation period (yrs)	5	Y	Additional initial robot cost (2 robots)	$	136,000	
			Total costs	$	636,000	T
			ROI (Total Savings/Total Costs for period)		710%	S/T

* Current weld task requires operator to work in a tight corner and in some cases weld or inspect with mirrors

** HMMR task documented operational speeds

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Current activity

- Transferring equipment to longer-term testing
- Support in-field testing and implementation
- Working with OEM to transfer technology through nationally recognized distributor

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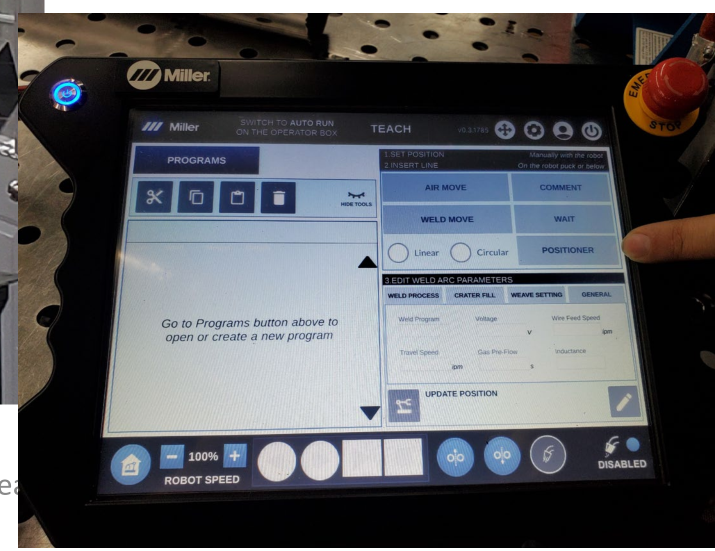
Miller Copilot™

- 18 month collaboration to develop Miller's Copilot
- AccuGuide™
- IntelliSet™
- Motion planning
- Program interface
- Future Opportunities
  - Integration: Sensors
  - Integration: Positioners
  - Integration: Linear Rails
  - Portability

Distribution A. Approved for public release: distribution unlimited

Integrated Positioner (Miller-sourced CoPilot + Positioner)



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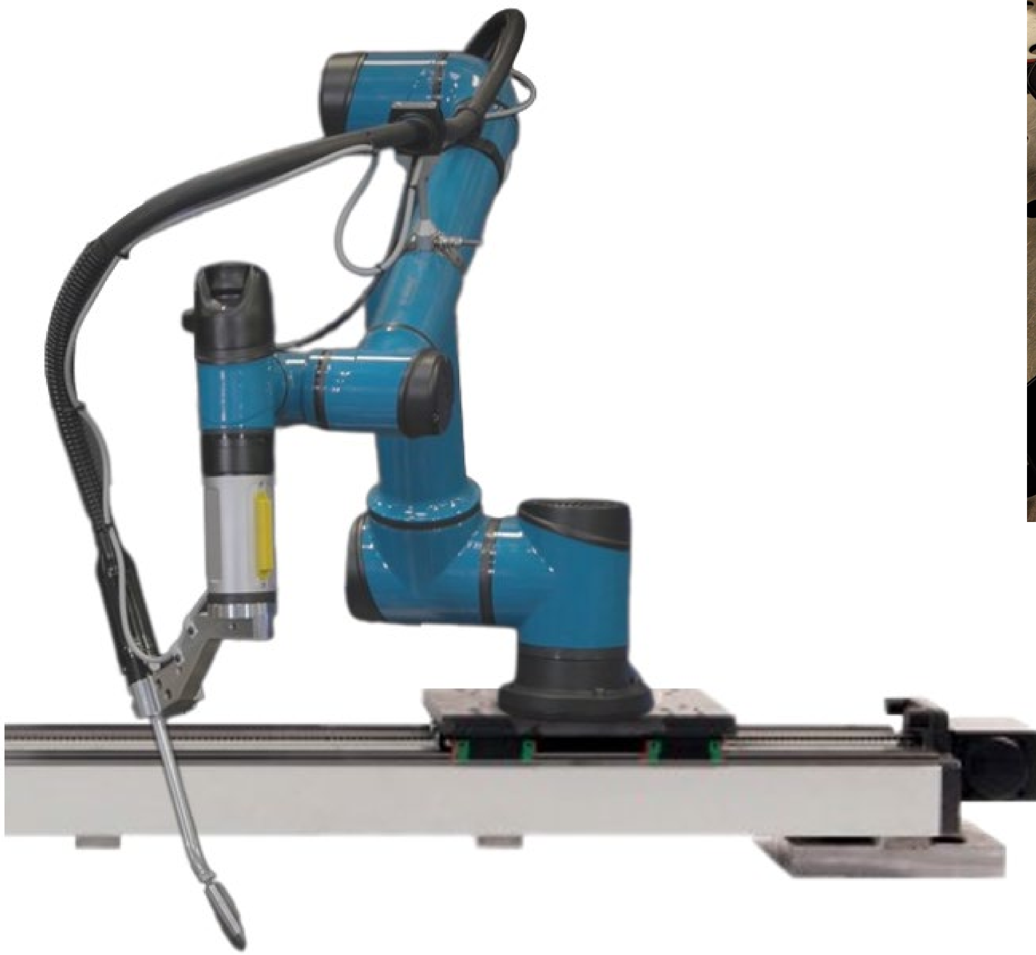
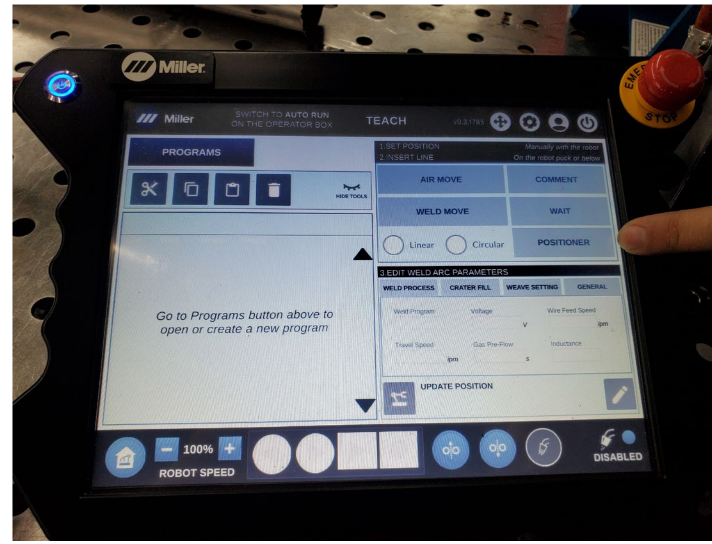
distribution unlimited

Integrating Extended-reach system (rail/track based arms)





- Other integration actions:
  - Onboard sensing
  - Seam tracking
  - Touch sensing, through arc seam tracking

Summary

- Robots / Cobots in manufacturing
- Multi-function shipbuilding robot – Mantech project update
- Sample Applications
- Review the NSRP RA Project TIA #2020-303
- Technology transitions to Miller Copilot
- Future integration opportunities of cobots in ship manufacturing

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Questions