College of Engineering
Department of Mechanical & Industrial Engineering

College of Engineering
School of Electrical Engineering & Computer Science

To Predict ▶ To Design ▶ To Perform

ME, ECE Capstone Design Programs

Team #15: 3D Printed Part Design and Build with Arc-Welding Metal Deposition

Michael Belanger (ME), Christian Bethea (ME), Samuel deGeneres (ME), Allen Eschete (ME), Tony Huynh (ECE), Unoma Okoye (EE)

Laitram® intralox® Jack Rettig

Objective

The purpose of this project was to improve the Wire-Arc Additive Manufacturing (WAAM) printing process and design and build two pressure vessels, one carbon steel and one aluminum, with a maximum allowable working pressure of 300 psi, according to the ASME Boiler and Pressure Vessel Code.

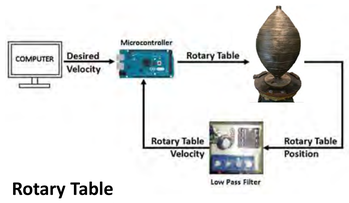
Background

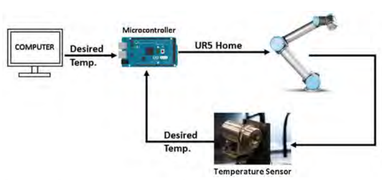
- ❑WAAM device designed and built by the 2016-2017 capstone team
- ❑Universal Robots UR5 robotic arm
- ❑Miller 350 Continuum GMAW welder
- ❑Steel – 0.035" ER70S-6 electrode
  - ❑ Shielding gas – 90% Ar - 10% CO_2
- ❑Aluminum – 0.035" ER5356 electrode
  - ❑ Shielding gas – 100% Ar

Engineering Specifications

Specification	Steel Goal	Steel Actual	Al Goal	Al Actual	Unit
Yield Strength	70	68	19	22	ksi
Print Time	11	41.5	11	47.5	hr
MAWP	300	507	300	507	psi
Interpass Cool Down Time	60	150	60	120	sec
Interpass Temperature	392	392	158	158	°F
Wall Thickness	0.21	0.21	0.4	0.375	in
Inner Diameter	12	11.5	12	12	in

Electrical and Computer



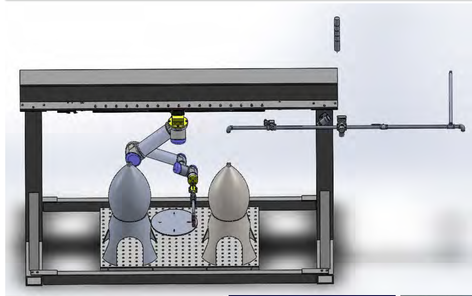


Rotary Table
The speed of the rotary table is inversely proportional to the radius of print. A low pass filter was developed to reduce noise and filter unwanted frequencies.

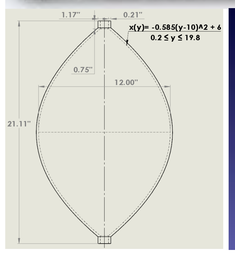
Thermal Sensor Control
The thermal sensor will measure the temperature of each weld layer. The UR5 goes to a home position until desired temperature is reached. Then, the UR5 will go to the next layer position.

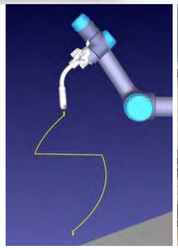
Microcontroller	Arduino ATmega2560 R3 board
Computer	RoboDK Interface
Temp. Sensor	MicroEpsilon CTLM-3LSF60-C3, 24VDC input voltage, 0-5V output

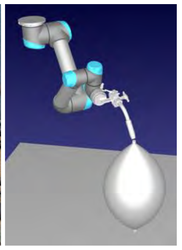
Embodiment

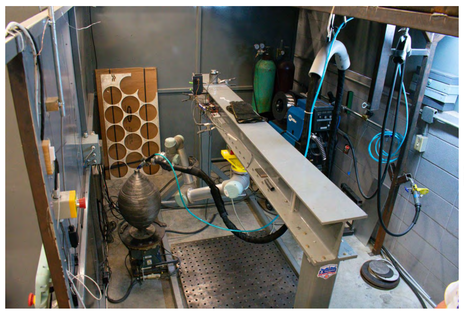


Part	Part Name
1	UR5 Robotic Arm
2	GMAW Welding Gun
3	Parabolic Vessel (Steel)
4	Parabolic Vessel (Aluminum)
5	Cooling System
6	Thermal Sensor
7	Stack Light Enclosure Indicator
8	Rotating Table





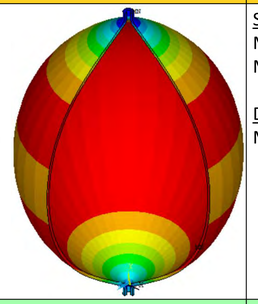
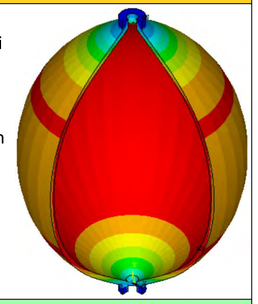
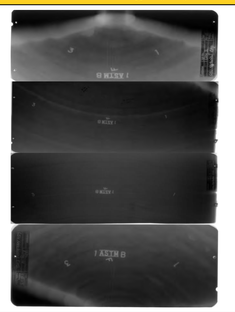
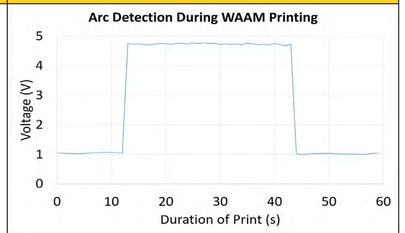




Manufacturing

Rotary Table	RoboDK Software	Tool Center Point (TCP)	Layer Cooldown	Thermal Sensor
• Adds degree of freedom • Reduces UR5 orientation singularities • Increases print volume height	• Creates tool path • Simulates tool path • Allows for starting and stopping print	• Allows accurate tool positioning • Allows printing at different tool angles	• Creates more uniform welds • Reduces weld bead dripping • Improves material properties	• Allows weld temperature monitoring and feedback

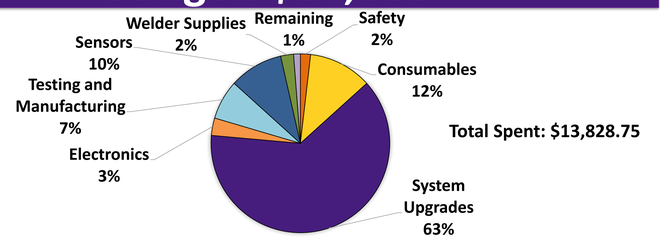
Testing & Analysis

FEA – Steel Pressure Vessel	FEA – Aluminum Pressure Vessel
Stress Max: 8419.48 psi Min: 166.37 psi Deflection Max: 0.001916 in	Stress Max: 5289.34 psi Min: 7.19 psi Deflection Max: 0.001812 in
	
HPT @ 429 psi: PASSED	HPT @ 429 psi: PASSED
Failure Pressure: > 725psi	Failure Pressure: > 725 psi
Weld Radiography	**Loss of Arc**
	
	Light sensor output during printing. Data collected for a single weld layer. Loss of arc at 1.02 V.

Safety Considerations

ANSI safety signs used to warn users and non-users of potential hazards associated with the WAAM device.
+ Weld status indication stack light integration

Budget: $14,000



Total Spent: $13,828.75

September	October	November	December	January	February	March	April
Learn WAAM system and perform steel test welds.	Design pressure vessel, ventilation, other improvements. Analyze possible solutions.	Finalize pressure vessel design and system improvements. Verify software use for system.	Install welding equipment.	Integrate new software and code. Installed air cooling system.	Integrate temperature sensor. Test weld aluminum. Steel material tests. Angled aluminum printing.	Created sensor aiming device. Print steel vessel. Aluminum material testing. Print aluminum vessel.	Pressure test steel and aluminum vessels. Create new GUI.

Sponsors: Dr. Dimitris Nikitopoulos, Mr. Scott Dailey, Mr. Jack Rettig

Adviser: Dr. Tryfon Charalampopoulos