Robotic Arc Directed Energy Deposition Additive Manufacturing

Robotic DED System Setups – User Experience with Multiple Configurations

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Approved for Public Release: Distribution is Unlimited

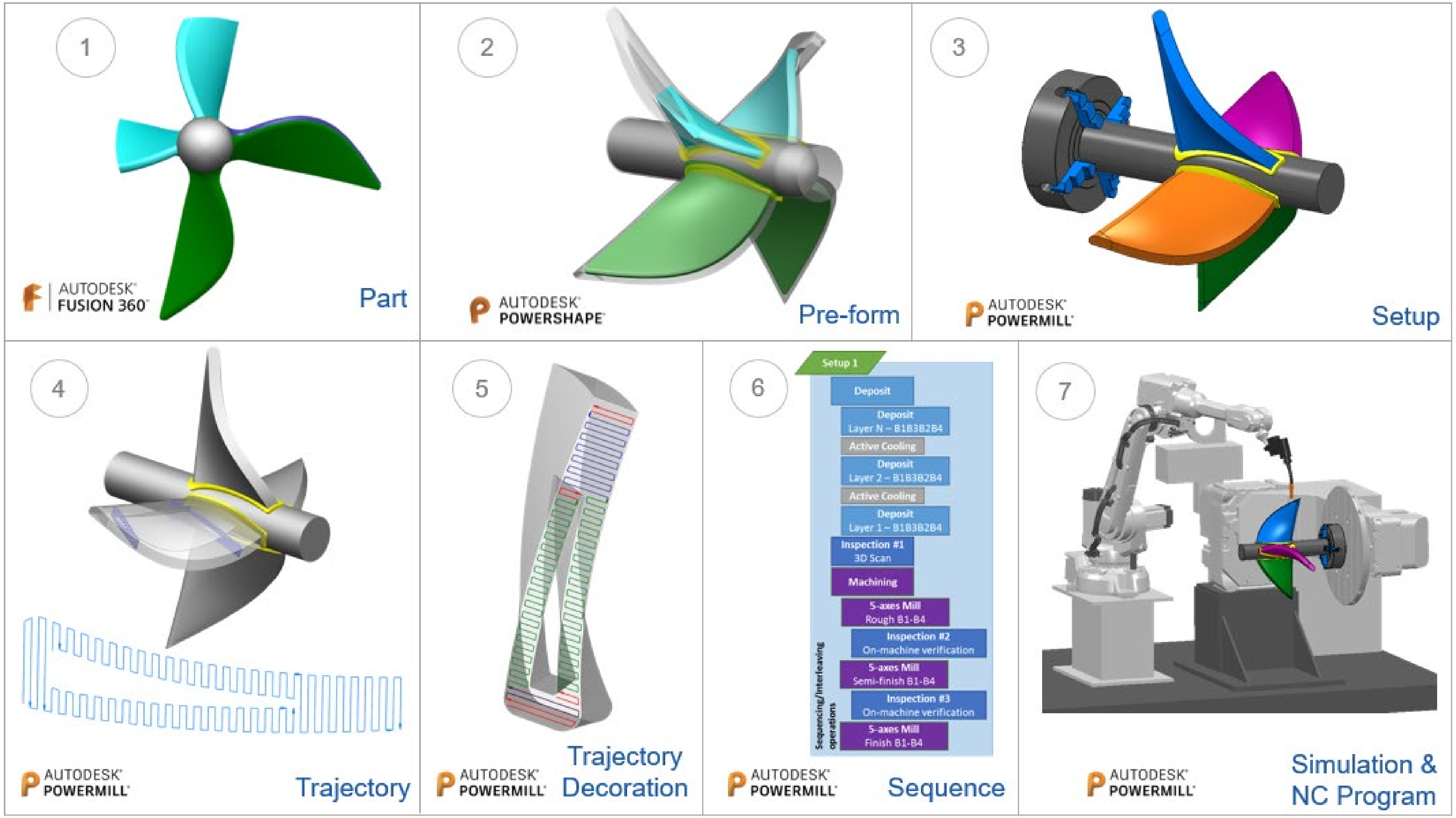
Acknowledgement

Much of the content presented was developed in the National Shipbuilding Research Program – Advanced Shipbuilding Enterprise (NSRP-ASE) Research Announcement (RA) Project 2019-375-004.

Digital Data Workflow

*Courtesy Autodesk

Part Programming Workflow



Digital Twin and Post Processor

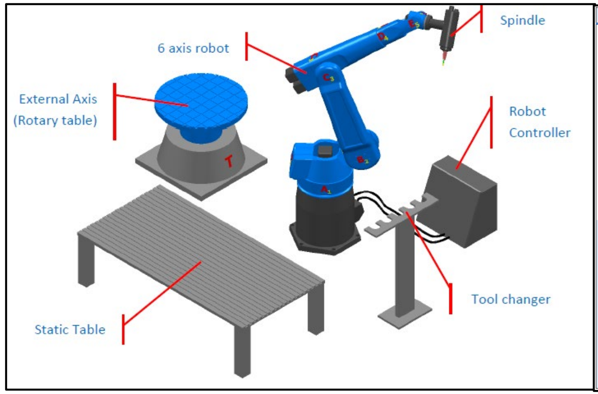
*Wikipedia

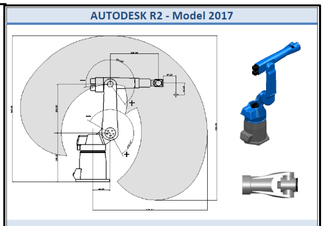
- A **digital twin** is a digital replica of a living or non-living physical entity. Digital twin refers to a digital replica of potential and actual physical assets (physical twin), processes, people, places, systems and devices that can be used for various purposes. The digital representation provides both the elements and the dynamics of how the device operates.

- A **post processor** is a unique "driver" specific to a CNC machine, robot or mechanism; some machines start at different locations or require extra movement between each operation, the post processor works with the CAM software or off-line programming software to make sure the G-Code output or program is correct for a specific machine. An instance of such a translation is often referred to as a "post." There will be a different “post” for each G-Code dialect the CAM software supports.

Building The Digital Twin

*Courtesy Autodesk





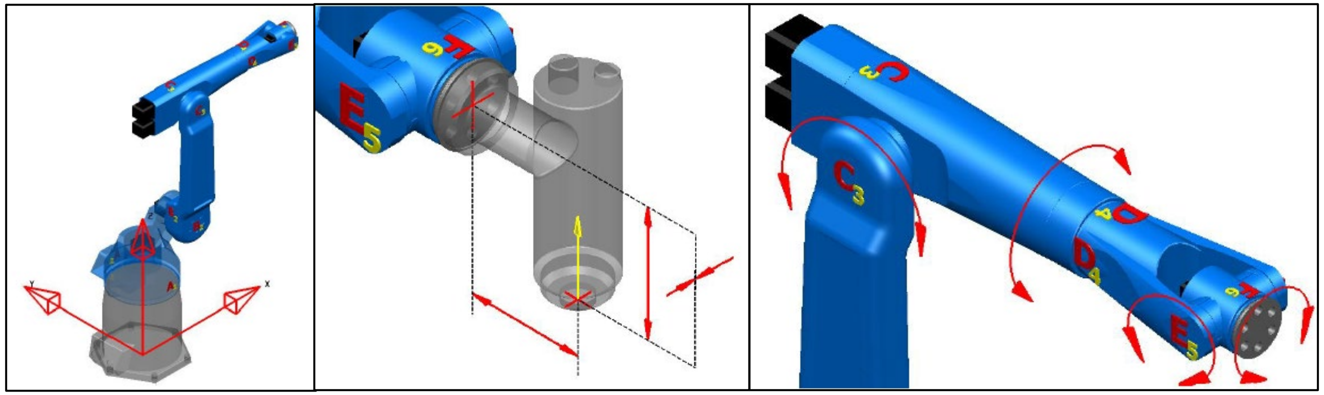
Robot Type	Autodesk R2 - Model 2017
Maximum load (center of gravity)	185 kg
Number of axes	6
Controller model	Autodesk controller 2017/R2
Position	Floor / Wall
Repeatability	± 0.04 mm
Robot weight	880 kg

Axes	Range	Speed
Axis 1 (A)	± 185°	112°/s
Axis 2 (B)	-50° / +100°	89°/s
Axis 3 (C)	- 215° / +70°	118°/s
Axis 4 (D)	± 360°	169°/s
Axis 5 (E)	± 130°	212°/s
Axis 6 (F)	± 720°	110°/s

Geometries (CAD models)

Spindle (head, tool)
External axes

Robot data sheet
Robot cell



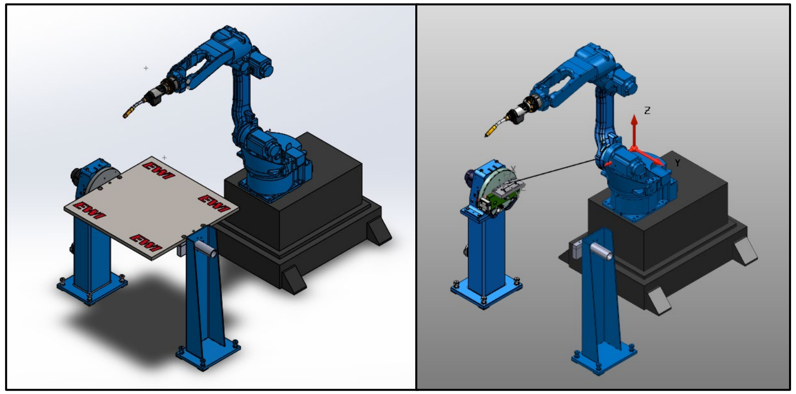
Coordinates, Workplanes, and Positions

Robot world
Zero position

Axis directions
Axis min/max

Spindle orientation
Tool attach point

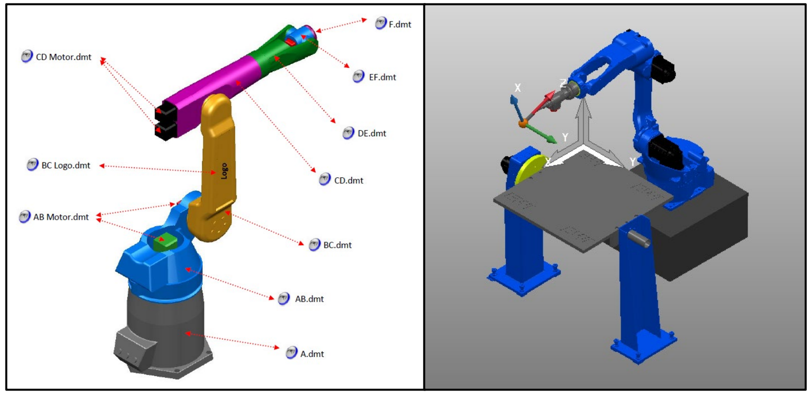
External axis position



Preparation of the CAD Model

SolidWorks for assembly

PowerShape for layering



Export entities

PowerShape for .mdt

```
<machine xmlns="x-schema:PowerMillMachineTool" POST="SimPost. ">
..<head_attach_point PART="head" …Coordinates… />
..<table_attach_point PART="table" … Coordinates … />
..<machine_part NAME="table" /> ➔ the part is on the table (floor)
..<machine_part>
  …List of static entities…
..</machine_part>
..<machine_part>
    …Robot Axis 1…
....<machine_part>
      …Robot Axis 2…
......<machine_part>
        …Robot Axis 3…
........<machine_part>
          …Robot Axis 4…
..........<machine_part>
            …Robot Axis 5…
............<machine_part>
              …Robot Axis 6…
..............<machine_part NAME="head" /> ➔ the tool is on the head (robot)
............</machine_part>
..........</machine_part>
........</machine_part>
......</machine_part>
```

PowerMill MTD file

Structure
Simulation

Attach points
Links

Developing the Post Processor

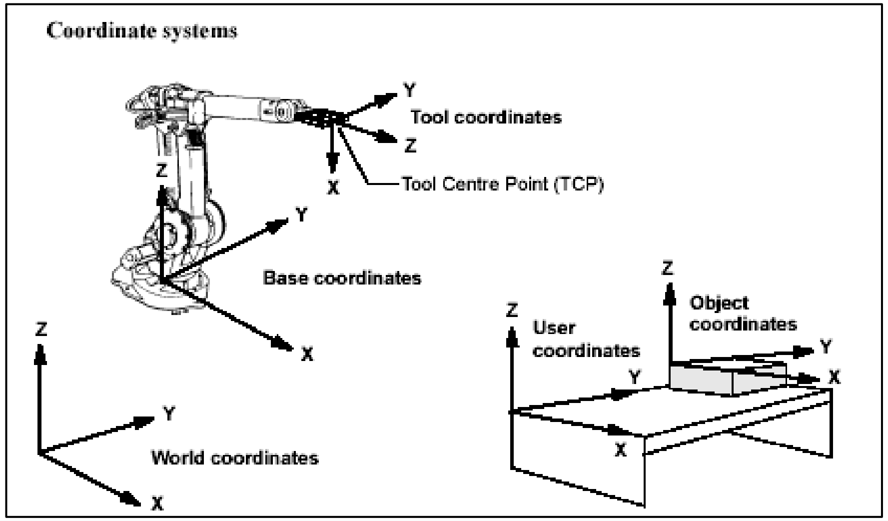
Toolpaths are created independent of the machine tool or Robot. Each toolpath is then processed through the PRI (PowerMill Robot Interface) for a specific **robot cell**, this is where the **external positioners** are controlled as well. The **orientation** of the **tool** or **torch**, **collision avoidance,** and **singularity avoidance** takes place in this step of the process. All this **robot motion** information is recorded along with **weld parameters, deposition feed rates,** and other parameters and saved in the RobSim file.

The fundamental job of the **post processor** is to take the RobSim file and **output** the **programs** translated into the specific language that each robot manufacturer requires along with the **weld commands** for the DED device attached to the **robot** which must be turned **on** and **off** at the appropriate points in the toolpath.

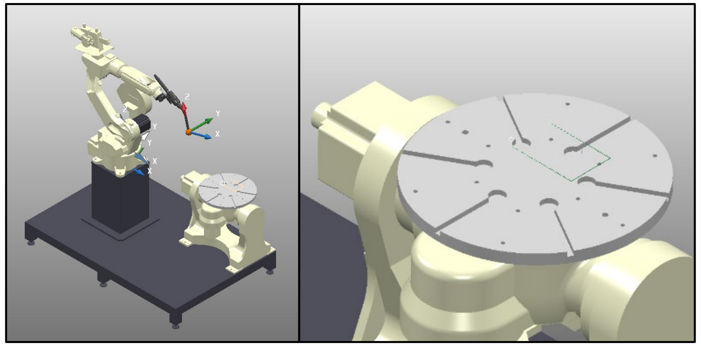
Some **robots** require **joint angles**, while others want **Euler angles**, some want **quaternions** or a combination of these parameters to suit their format. The **post processor** does the math and formats everything to suit each robot manufacturer including **splitting** of programs into **main** and **sub-programs** of the appropriate length, etc.

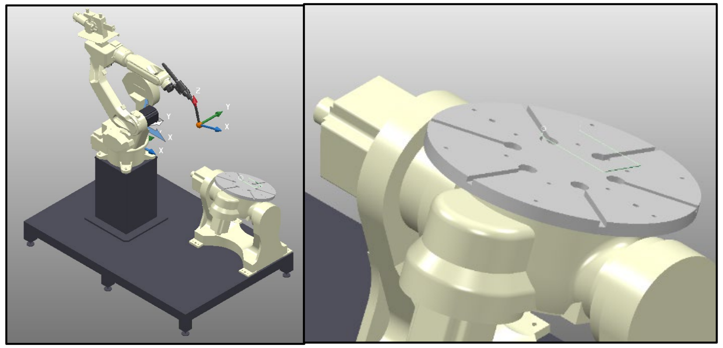
The **programming language** used by PRI Post Processor is XML.

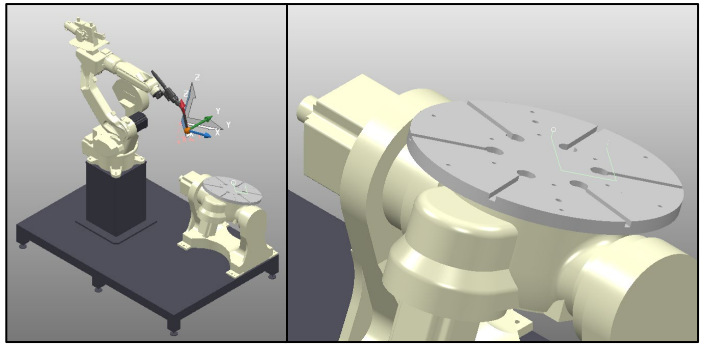
```
<?xml version="1.0" encoding="utf-8"?>
<Config>
  <PRIPost Version="3.0" />
  <!-- -->
  <Robot Manufacturer="NACHI" Name="OTC" Part="TABLE" />
  <!-- -->
  <Notes>
    <![CDATA[EWI OTC Weld with Positioner 06/18/2020]]>
  </Notes>
  <!-- -->
  <!-- These are user define parameters -->
  <!-- Name      = Name of the user parameter -->
  <!-- Group     = Group in which the variable must be displayed -->
  <!-- Visible   = is the variable displayed ? -->
  <!-- Variable  = Name of the variable used in the postprocessor -->
  <!-- Value     = Default value that can be edited by the user -->
  <!-- Unit      = Unit to display -->
  <!-- Tag       = Tag used to link system variables to the user define parameter -->
```



Calibrating and Validating the Post

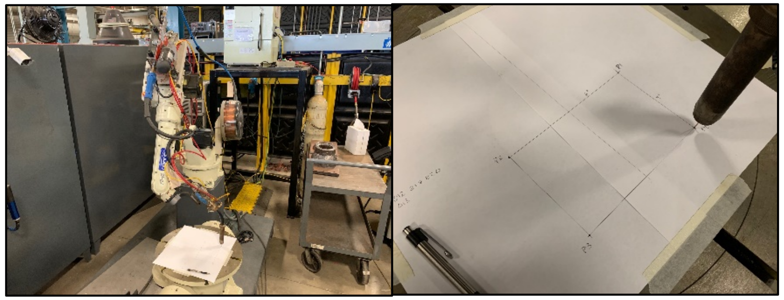


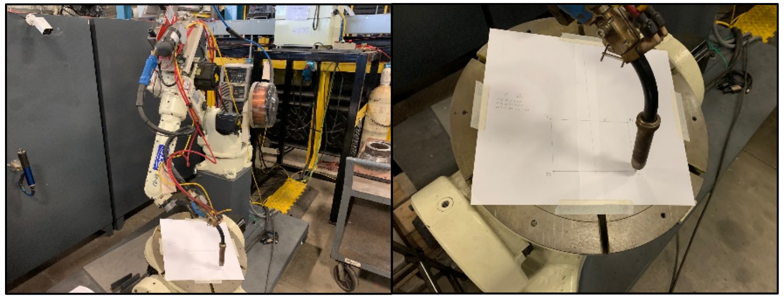




Create a measurable toolpath digitally

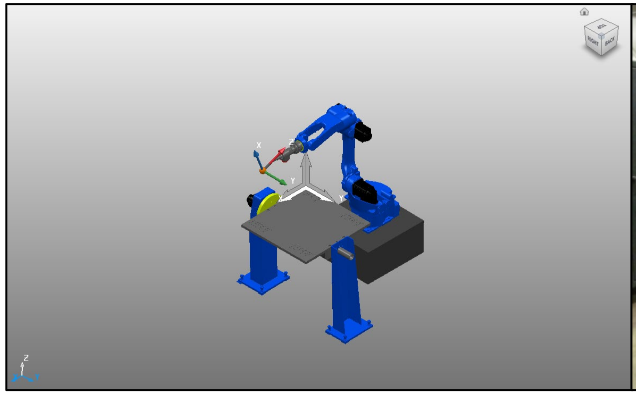
E1 = 0-deg	E2 = 0-deg
E1 = 20-deg	E2 = 0-deg
E1 = 20-deg	E2 = -40-deg

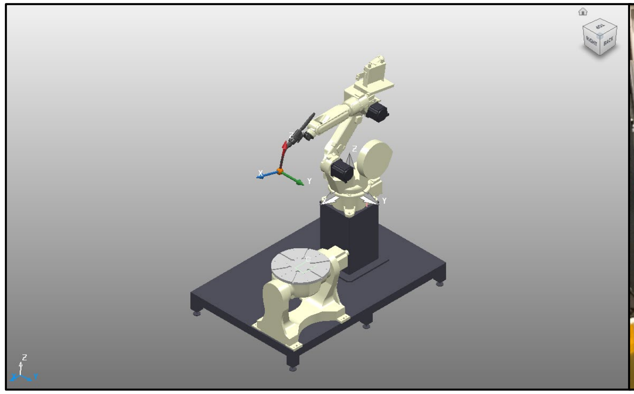




Confirm physically

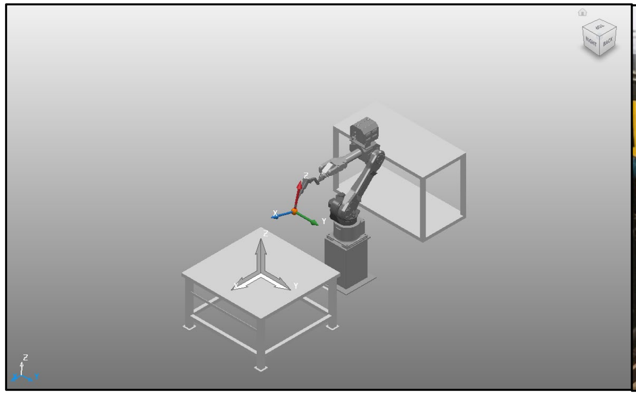
Robots/Posts



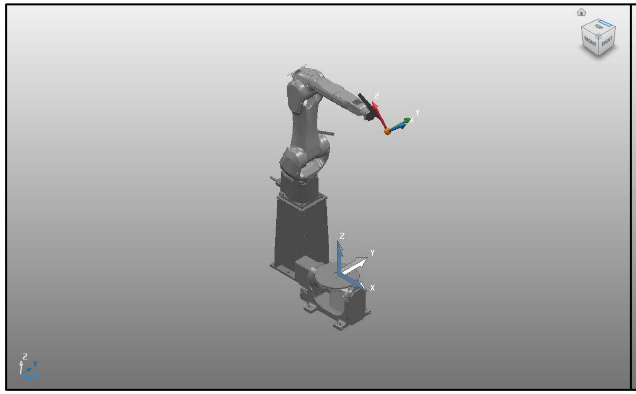
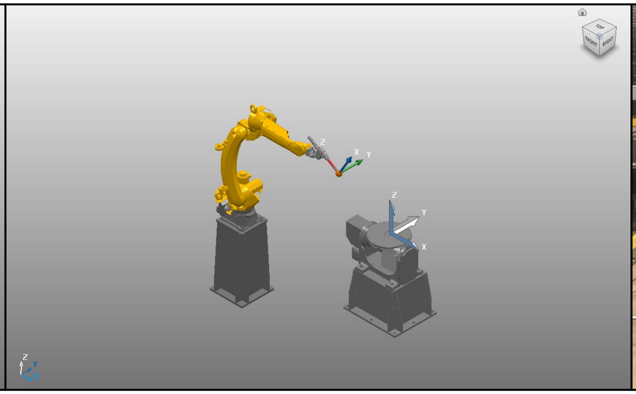
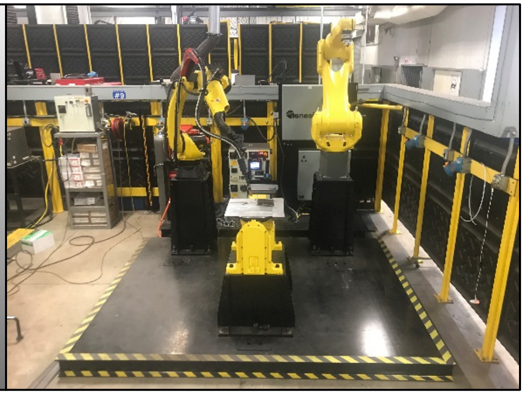


System	EWI Responsible, Integrators Support		DSI Responsible, EWI Support		EWI & DSI Responsible
	Robot Model Provided	Sample Robot Program Provided	PowerMill Simulation Model	Post Processor	Simulation Model and Post Processor Confirmed Via Testing
Motoman Fronius	Yes	Yes	Finished	Finished	Finished
OTC GMA-P	Yes	Yes	Finished	Finished	Finished

Robots/Posts

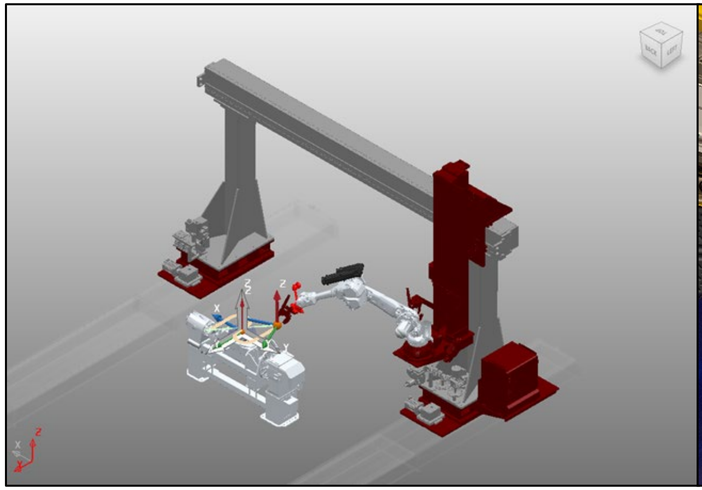



FANUC

System	EWI Responsible, Integrators Support		DSI Responsible, EWI Support		EWI & DSI Responsible
	Robot Model Provided	Sample Robot Program Provided	PowerMill Simulation Model	Post Processor	Simulation Model and Post Processor Confirmed Via Testing
Fanuc Lincoln	Yes	Yes	Finished	Finished	Finished
Genesis Fanuc	Yes	Yes	Finished	Fanuc Fronius Finished	Fanuc Fronius Finished

Robots/Posts



System	EWI Responsible, Integrators Support		DSI Responsible, EWI Support		EWI & DSI Responsible
	Robot Model Provided	Sample Robot Program Provided	PowerMill Simulation Model	Post Processor	Simulation Model and Post Processor Confirmed Via Testing
Navus ABB Gantry	Yes	Yes	Finished	Finished	Finished

Real World Challenges – Multiple Systems

MOTOMAN
A YASKAWA COMPANY

<u>Single Robot – 6 axis + 1 axis turn</u>

- Creating user frames to match digital twin
- Master user frame (MUF) was a challenge to create physically.
- No program conversion

Chris Anderson – Technical

OTC

<u>Single Robot – 6 axis + 2 axis tilt/turn</u>

- No user frames
    - DSI/EWI had to convert robot zero to positioner zero.
- One program conversion

Jason Robinson – Technical

Real World Challenges – Multiple Systems

FANUC

<u>Single Robot – 6 axis</u>

- Only issue was singularity due to torch setup.

<u>Dual Robots – 6 axis + 2 axis tilt/turn</u>

- Issue with linking positioner, need MUF
- Issue with multiple coordinate systems

One program conversion

Genesis – Technical

CLOOS

<u>Single Robot – 7 axis + 2 axis turn</u>

- In-process in collaboration with OSU

Mark Simmons – Technical

Ongoing Development - Advanced Systems

<u>Single Robot – 6 axis + 3-axis gantry + 2-axis tilt/turn</u>

- Gantry needs to be laser measured for precise accuracy.

Navus – Technical

Questions