

# Manufacturing the Future – Ensuring Prosperity and Security

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# Acknowledgements

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AUTOMATION

# Innovating technology faster than competition can copy

**Vision:** Rapid innovation, ensuring US dominance in advanced manufacturing

**Mission:** Identify, scale-up and integrate critical technologies for new and emerging advanced manufacturing sectors

Hybrid manufacturing and Machine Tools

Metal powder bed

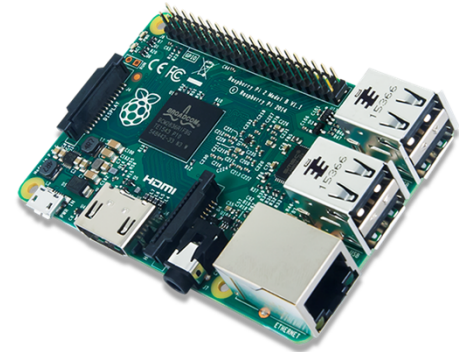
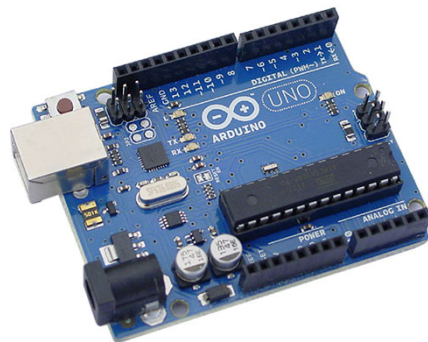
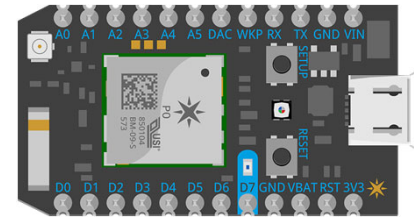
Large-scale polymers

Digital discipline

Metrology

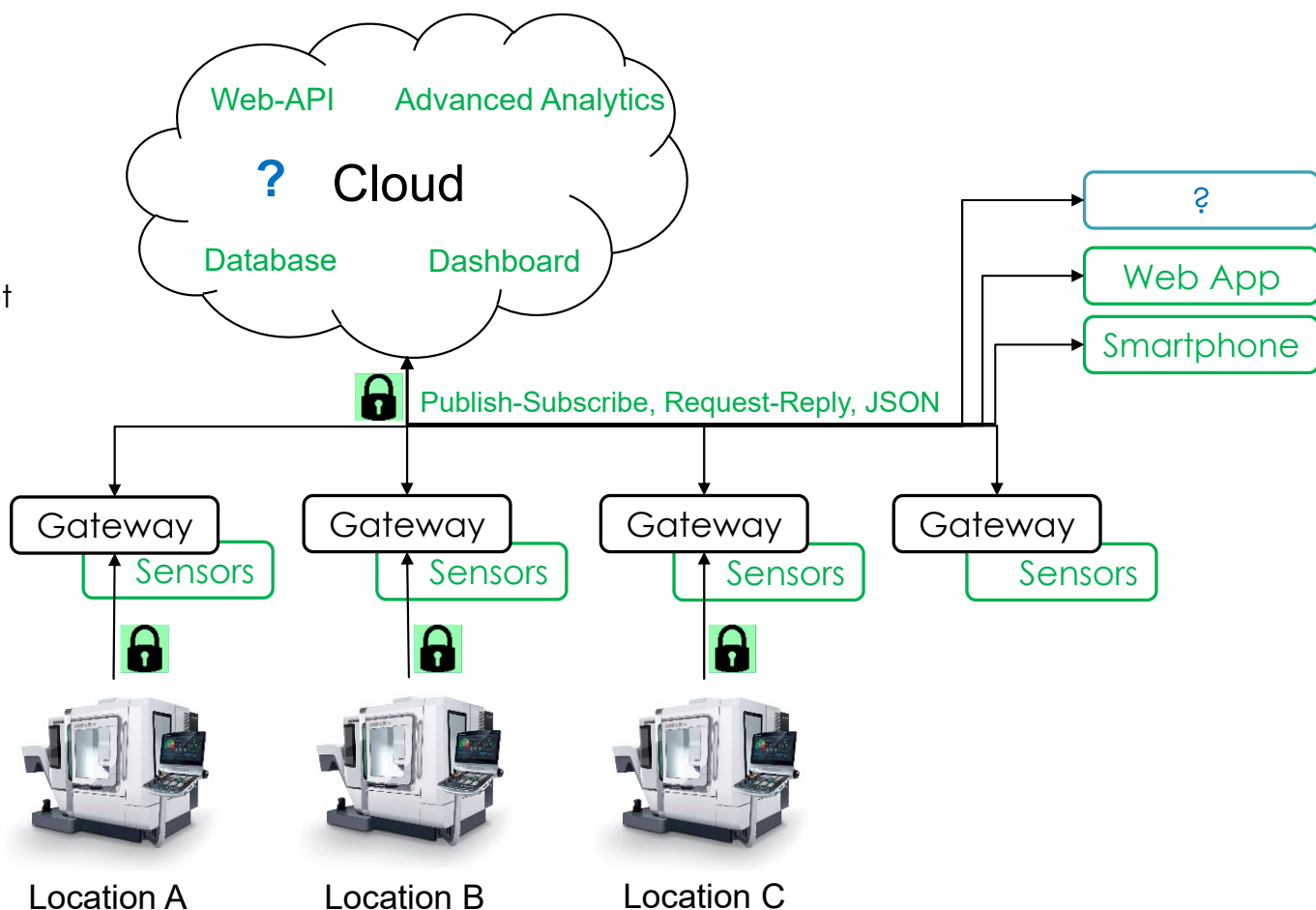
# Ubiquitous Sensing, Big Data & AI

- Embedded computing platforms
  - Arduino (Real-Time DSP)
  - Raspberry Pi (LINUX Platform)
  - Particle Photon (Cloud-Based Platform)
- Low cost / disposable / rapidly upgradable
- Sensors
- Sensors
- Sensors



# Next Generation Architecture

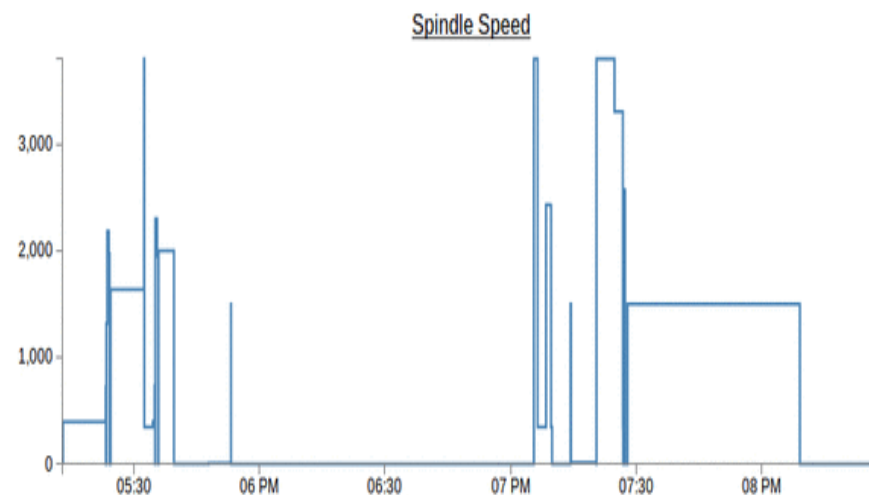
- **Secure, efficient, and real-time cloud operations**
- Integration of **REST/HTTP (request-reply)** and **MQTT (publish-subscribe)**
  - Compatible with majority of Internet services
  - Allow **machine-to-machine** and **machine-to-cloud** communication
  - Access with **no need of static IP** address
- **Integration of Web-APIs**
  - Twilio, GoogleScripts, IFTTT, AWS Lambda (Alexa)
  - Shock monitoring system (HFDA)
- **Fog computing and cloud computing**
  - Machine utilization
  - Number of parts and cycle time computation



# Big Data Generation – On Board Sensors

- Website for accessibility
  - List of machines with images as links
  - Review machine programs
  - Graphs plotted from near real time data

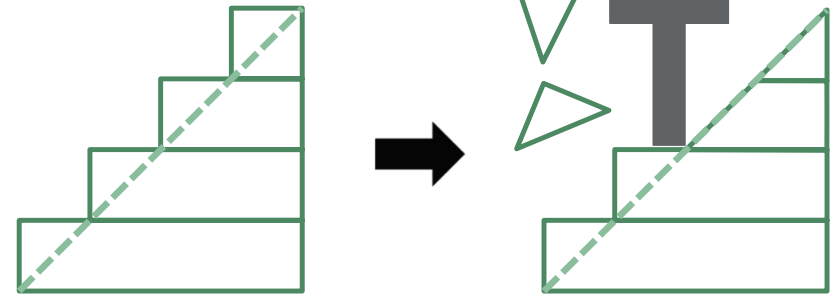
## List of Equipment



# Hybrid Manufacturing

- Combination of additive (Deposition), subtractive (Machining), and inspection in a single machine tool
- Achieving Higher Productivity & Better Surface Finish

-- Intended surface

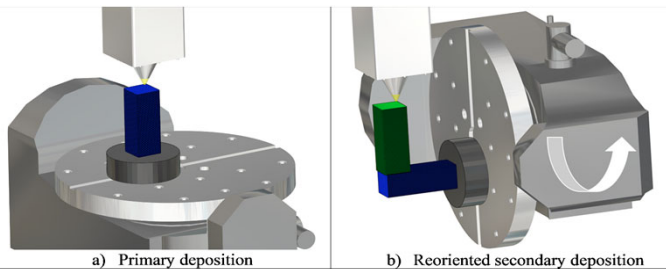
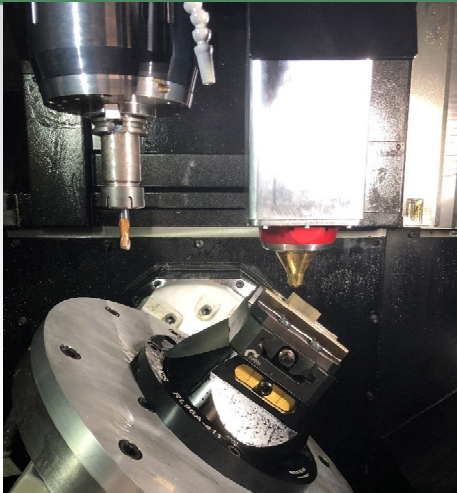


Printed near net shape



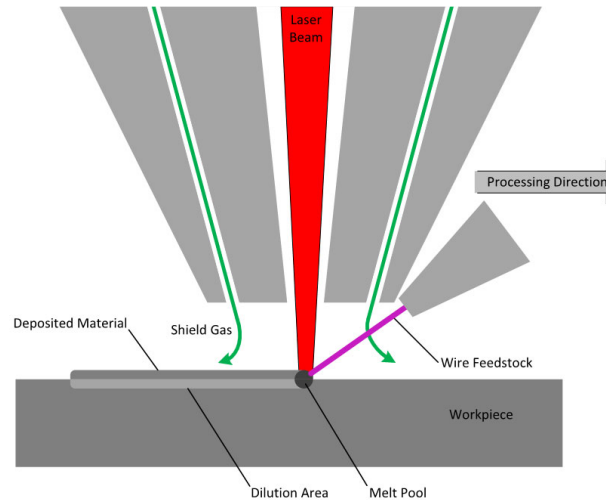
Machined surface

## Easily Reconfigured



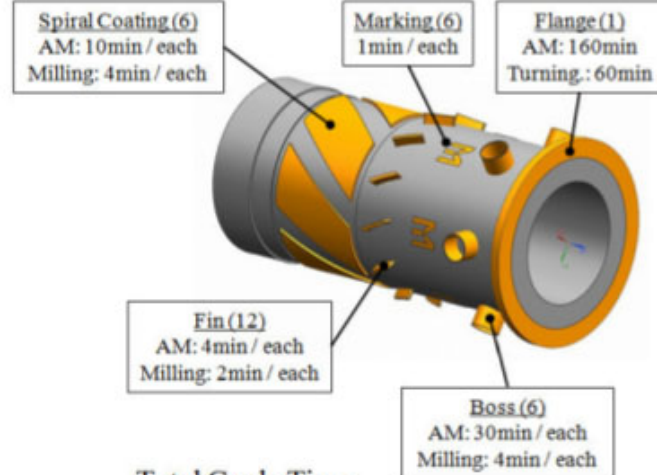
## Various Feedstock

- Additive:
  - Blown-powder (~0.5 lb./hr.)
  - Wire-feed (~5 lb./hr.)
- Subtractive: Traditional machining



## Lower Cost

Material (Substrate) : 316S31 + AM : Inconel 718



### Total Cycle Time

AM: 454min / Machining: 180min

Traditional: \$90,000

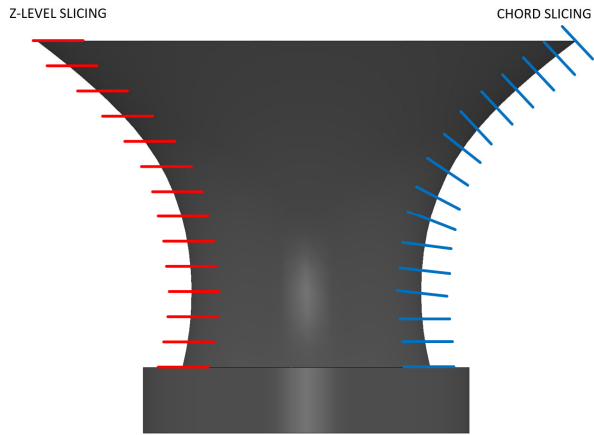
Hybrid: \$2,500

**97% Material Cost Reduction**

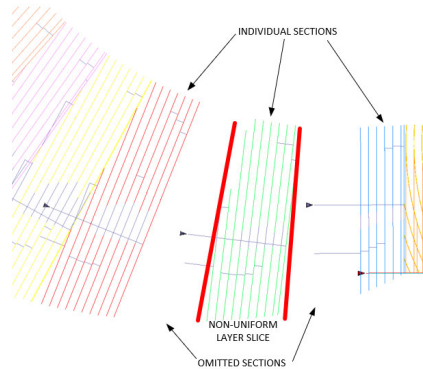
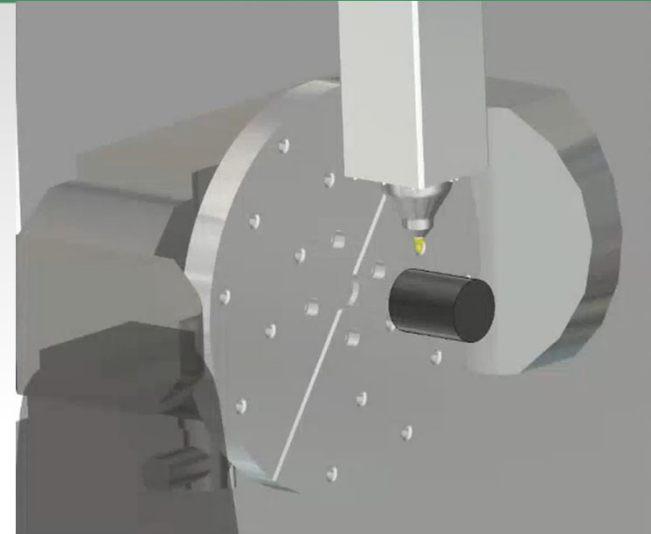
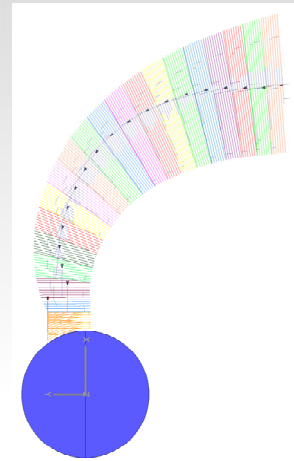
T. Yamazaki, "Development of a hybrid multi-tasking machine tool: integration of additive manufacturing technology with CNC machining," *Procedia Cirp*, vol. 42, pp. 81-86, 2016.



## Chord Slicing - Autodesk

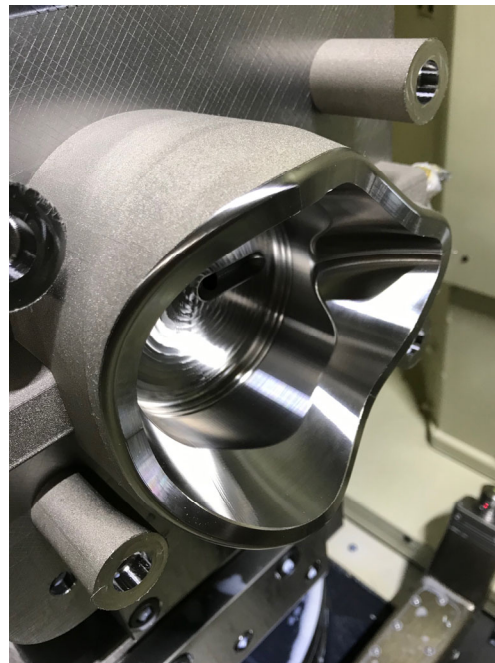


## Non-Uniform Layer Slices – Open Mind

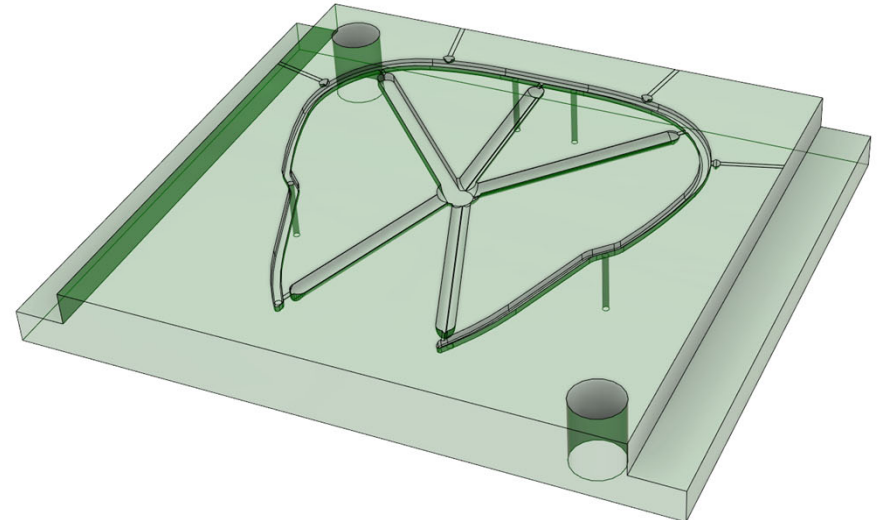
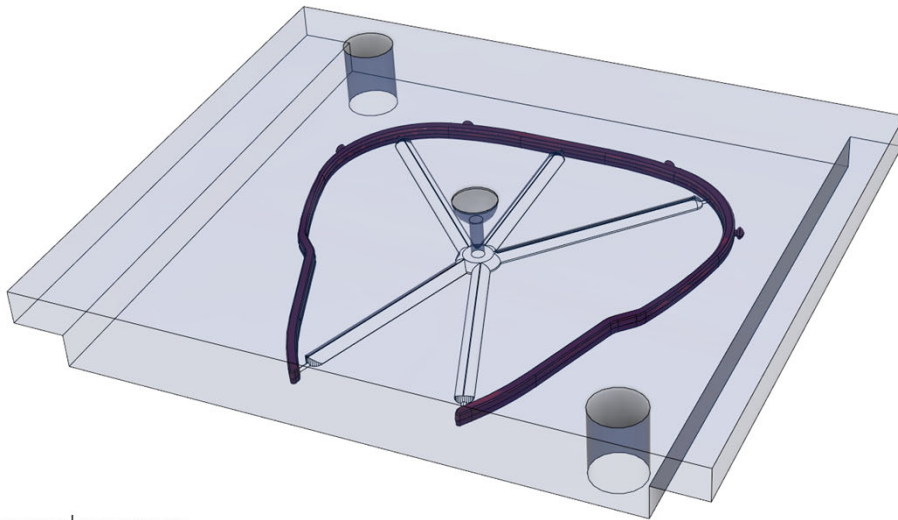
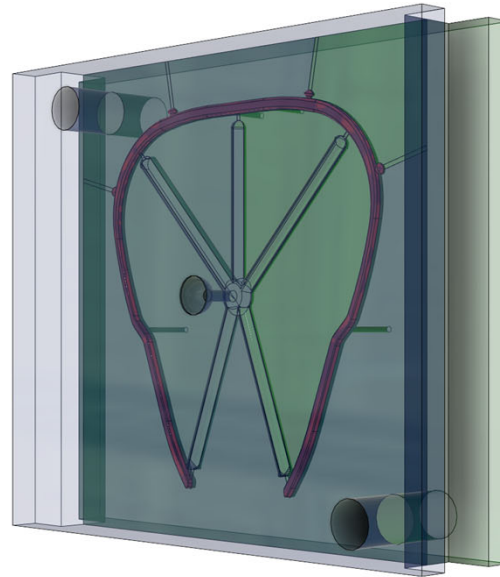


# COVID19 Manufacturing Demonstrations at ORNL

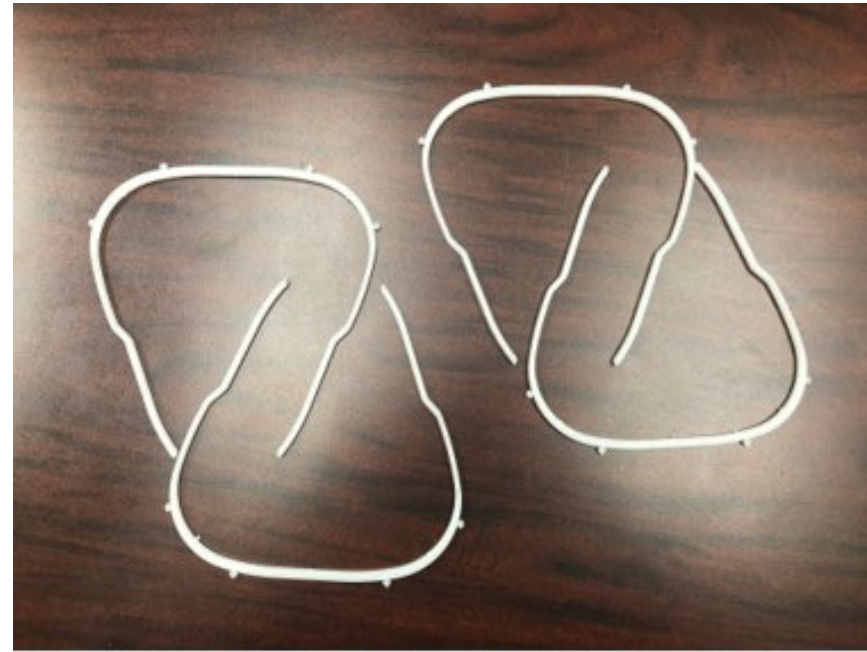
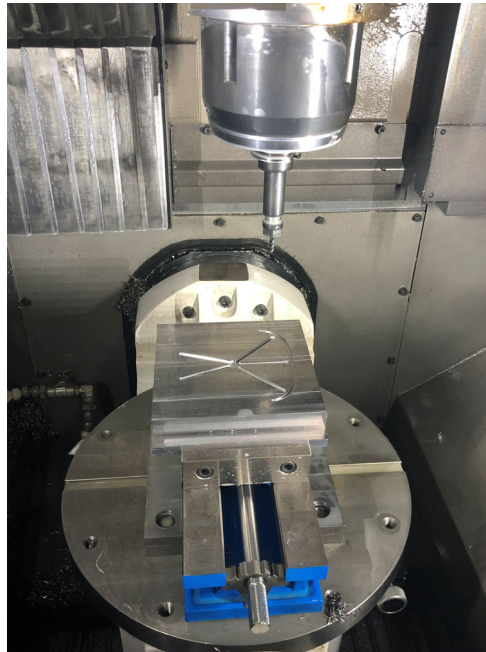
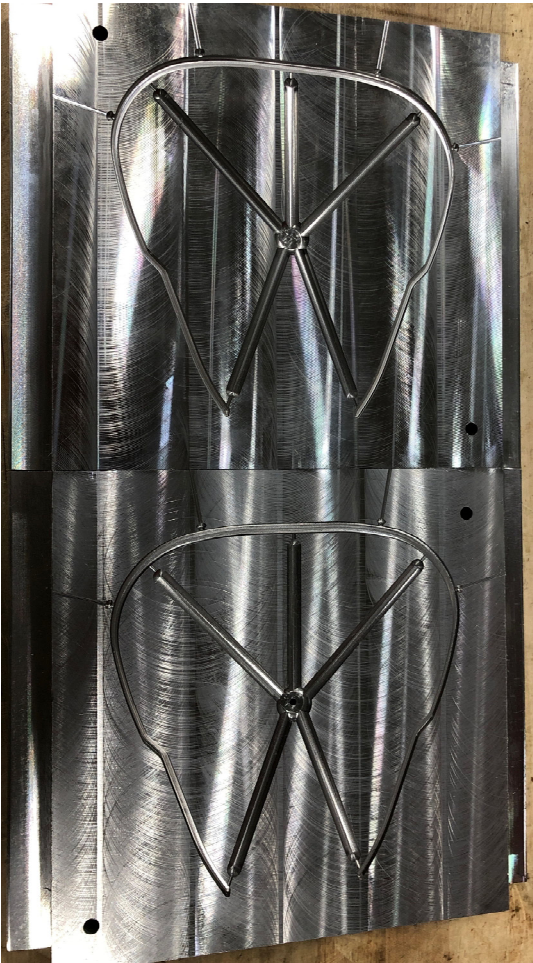
- Face Shields
  - DeRoyal
- Test Tubes
  - Denso
  - Coca-Cola
- N95 Material
  - Hills Inc.
- Masks
  - DeRoyal



# Face-Shield Mold



# Face-Shield Mold



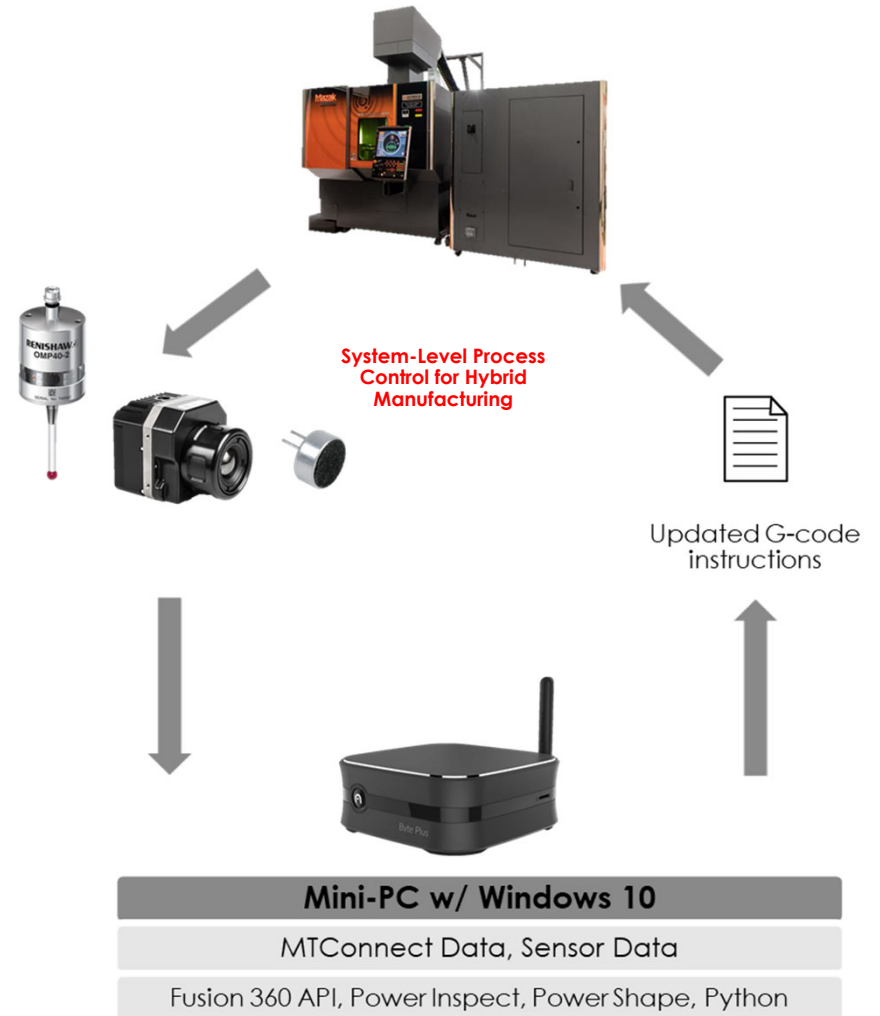
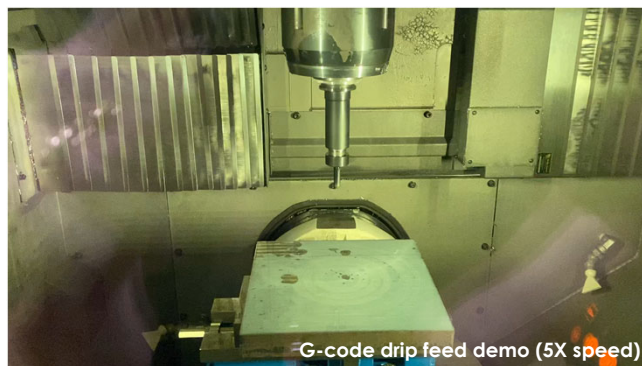
# Feedback Control Flow Architecture

## Edge-driven system level control

- G-code drip feed process
- Parameter and macro modification

## Modular components and interface access

- Standard, industry accepted protocols
- Goal, capabilities applicable to any system

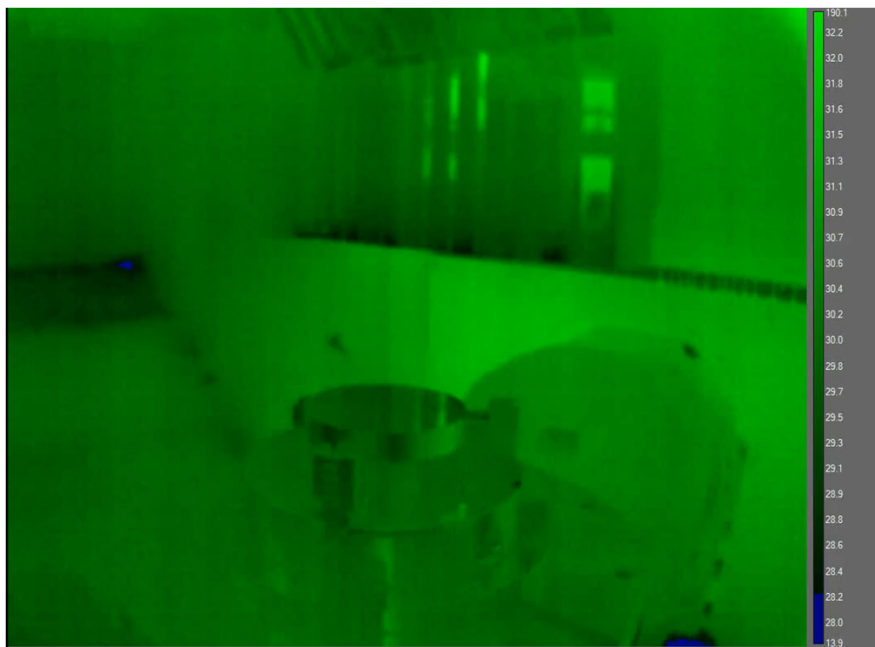


# Feedback Mechanisms for Closed-Loop Control

## In-situ Process Modifications

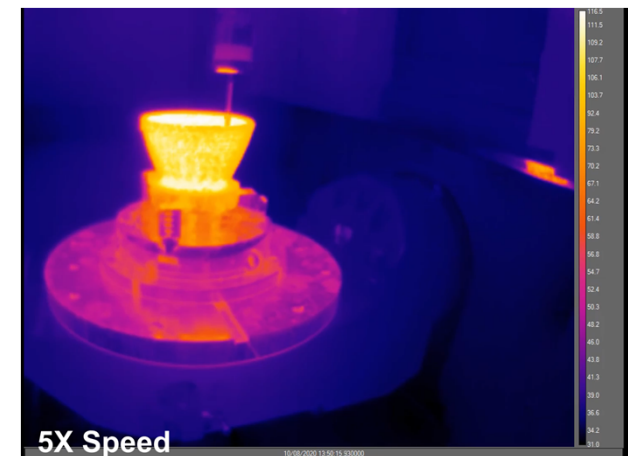
### Thermal Imaging

Thermal monitoring during print operations

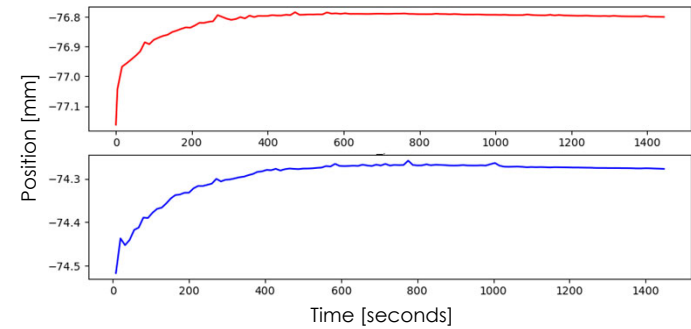


### Automated Geometric Inspection

Continuous inspection during cooling to monitor distortions over time



Distortion Steady-State Position

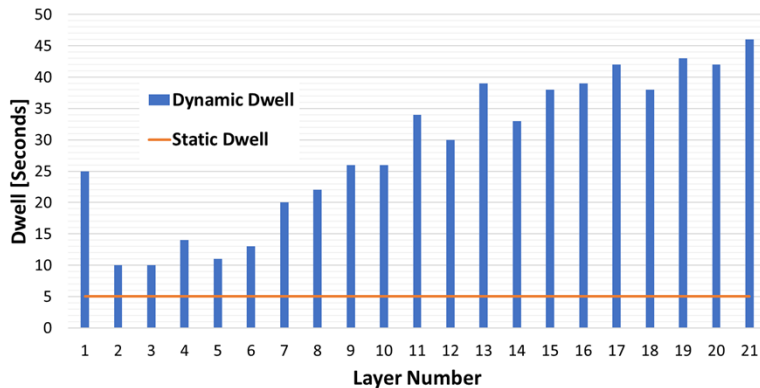
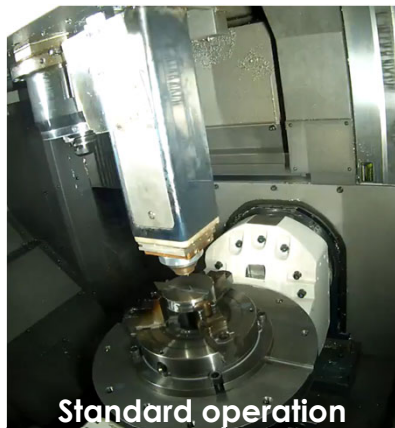


# Feedback Mechanisms for Closed-Loop Control

Enhanced, Data-Driven Operations

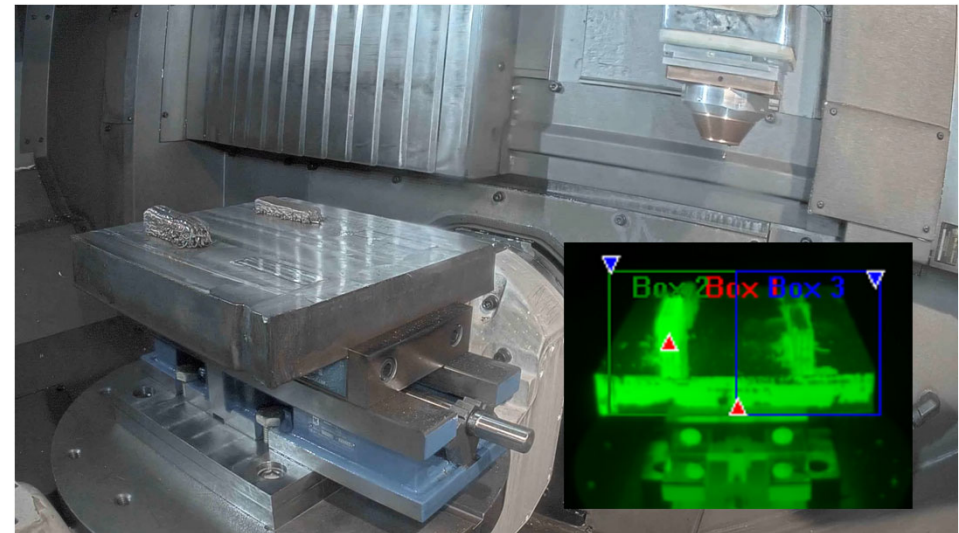
## Dynamic Dwell for Thermal Control

Fabrication of thin-wall structures with dynamic thermal control



## Multi-Part Thermal Operation

- Fabrication of 2 independent components with thermally-driven closed-loop control architecture
- Allows hybrid fabrication of N independent components within single build space



## The Building Blocks for Democratization

- Securely get the design and production information from customer
- Collect production data for digital passport, and for process validation and improvement.
- Make the part in a secure fashion and ensure that it has a valid digital passport
- Enable legacy systems
- Leverage XR to ensure safe and secure operations
- Control/store critical information in a secure location
- Create the recipe, and it is not a unique recipe
- Enable next generation production operations
- Perhaps a new business mode...

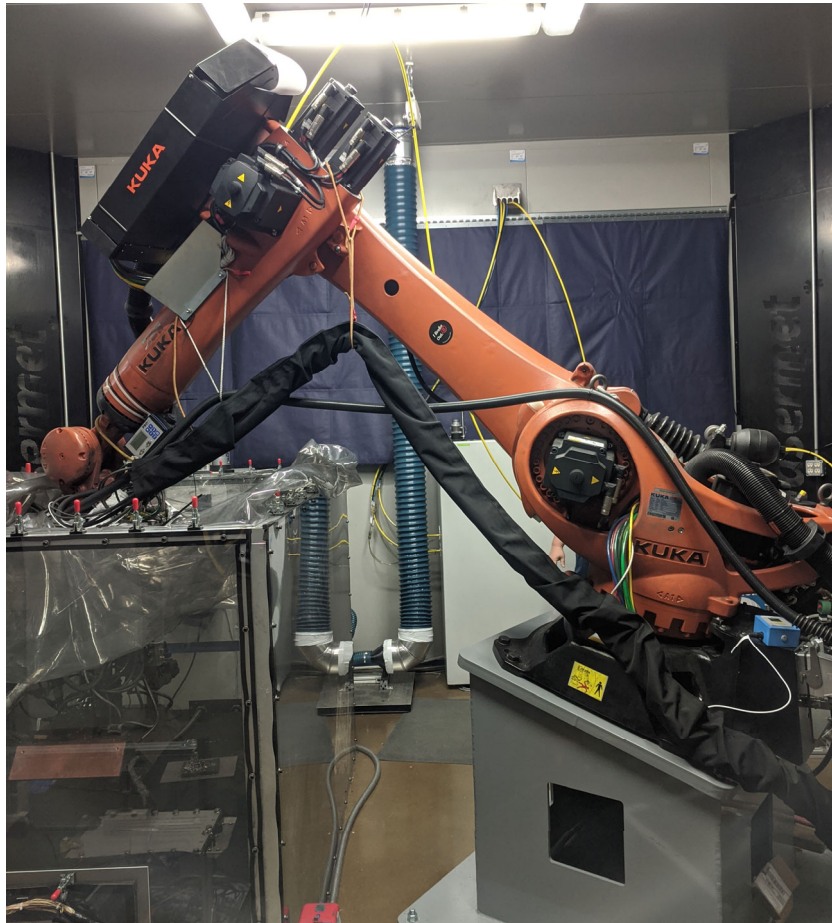
## The Ride Share Example

- Connecting the customer to the supplier
- Born qualified / digital passport
- Leveraging and extending the capabilities of a well-trained workforce





# When am I Going to Lose my Job?



# Back to the Big Picture

- Digital thread is a two-way street
  - Getting data for ML/AI
  - WFD capabilities (especially VR/AR/XR)
- Must deploy rapidly (faster than the competition)
  - Learning from production and field deployment
  - Generative design and manufacturing
  - Human providing the starting point
- Leverage Cloud/Fog/Edge for Compute/Communicate/Storage
- Must weave in cybersecurity
- Protection of proprietary and classified information
- Must support the ecosystem (SME/Middle class)

**“In times of change, learners inherit the earth; while the learned find themselves beautifully equipped to deal with a world that no longer exists.” (Eric Hoffer 1902-1983)**

