ADDITIVE MANUFACTURING OF HOT STAMPING DIES

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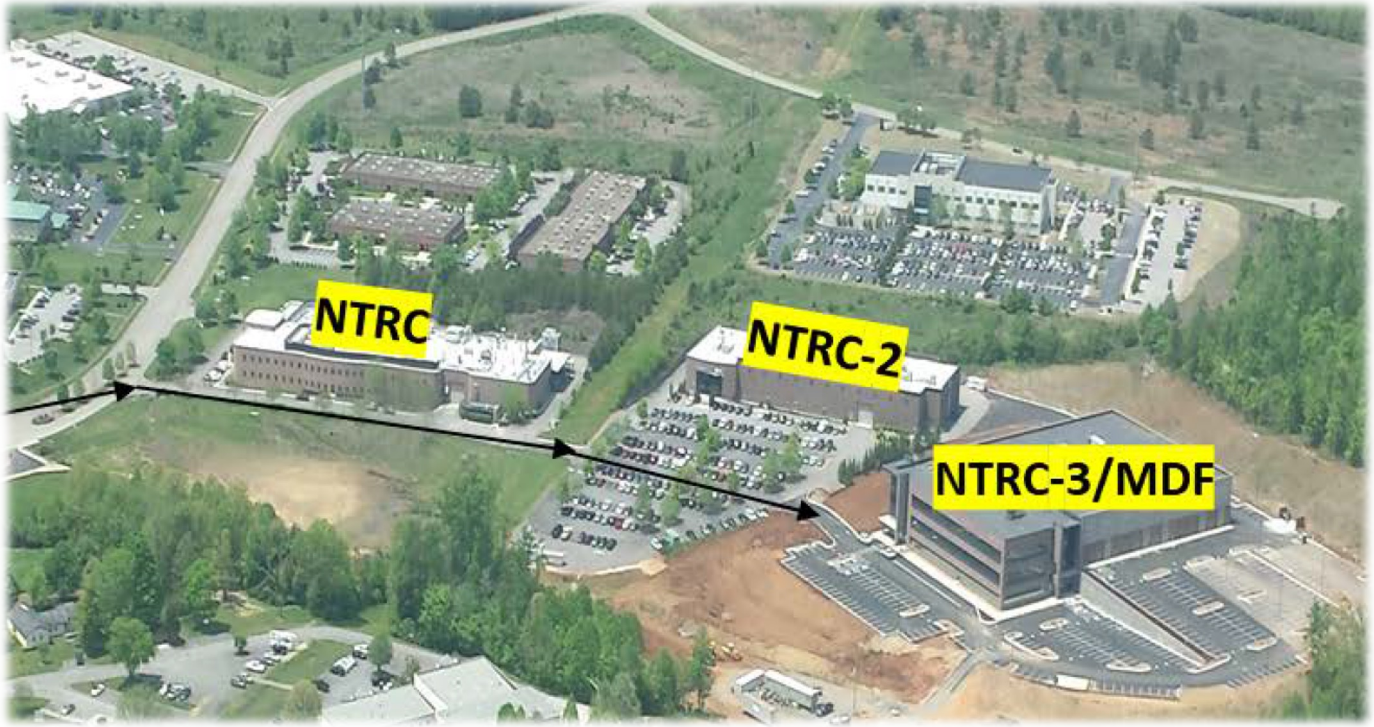
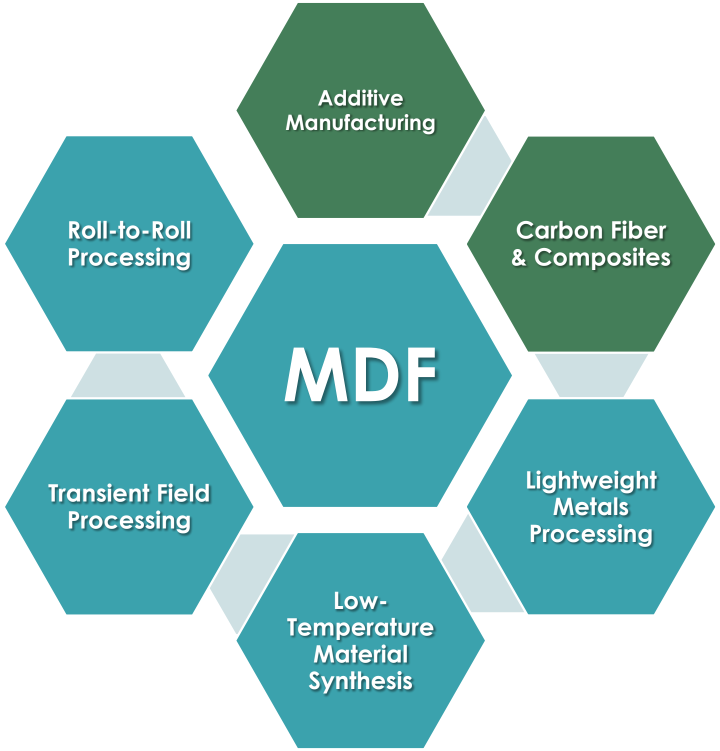
Additive Manufacturing of Hot Stamping Dies via Wire-arc Technology
OAK RIDGE National Laboratory
MANUFACTURING DEMONSTRATION FACILITY
DTS
DIENAMIC TOOLING SYSTEMS
TOOLING SYSTEMS GROUP
LINCOLN ELECTRIC
Additive Solutions

Manufacturing Demonstration Facility

Providing leading edge technology and business solutions for industry





Main Focus on *Additive Manufacturing*

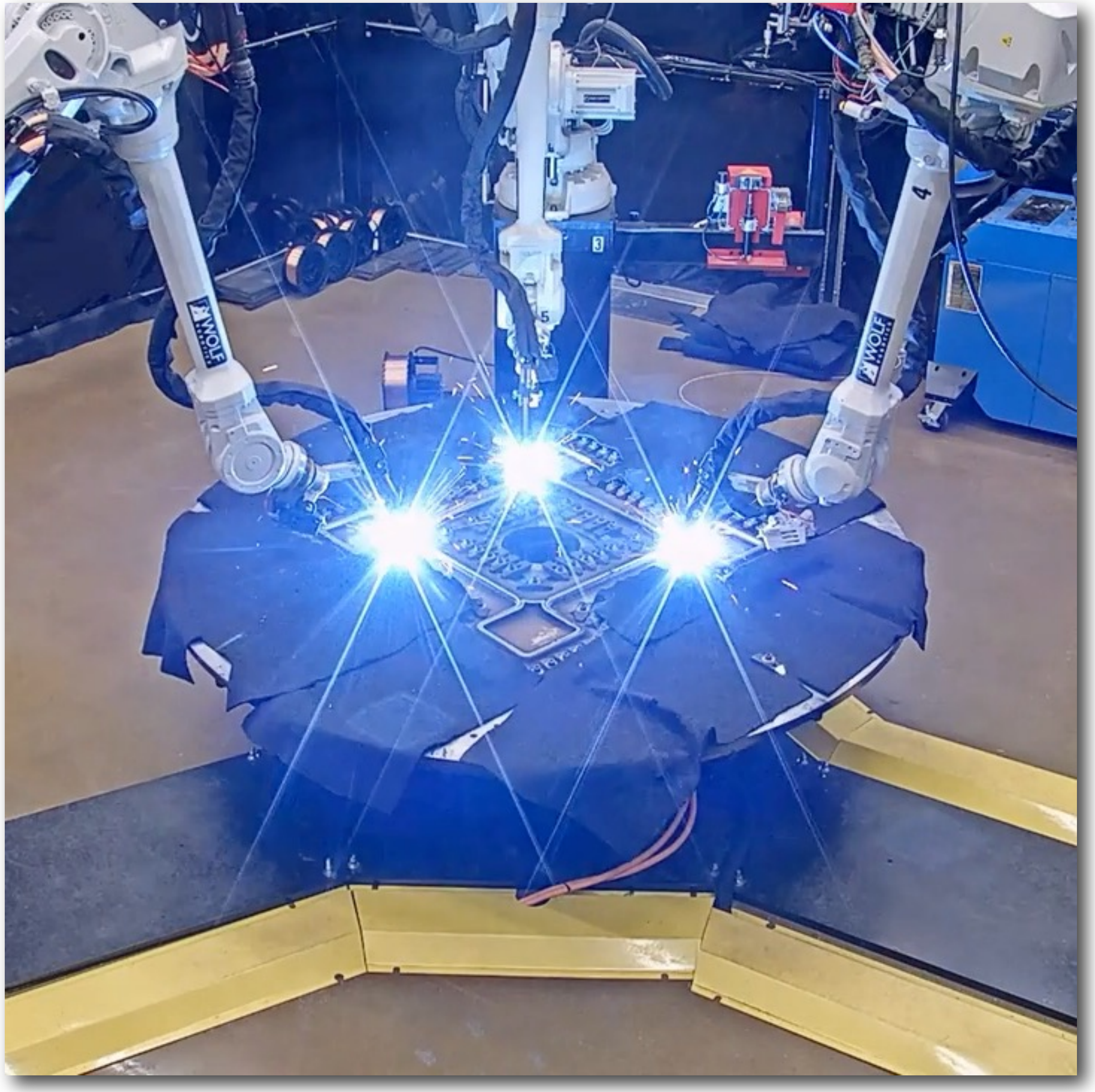
- **ORNL ~$ 2B Budget, ~6000 staff, ~4000 guests**
- **ORNL – Supercomputing – Frontier** the fastest supercomputer in the world
- **ORNL – Spallation Neutron Source** - accelerator-based neutron source
- **ORNL – High Flux Isotope Reactor**
- **ORNL – Manufacturing Demonstration Facility –** everything manufacturing

Manufacturing Demonstration Facility

- Cars
- Houses
- Mobile homes
- Big molds
- Submarines
- Tooling/fixtures
- Structures

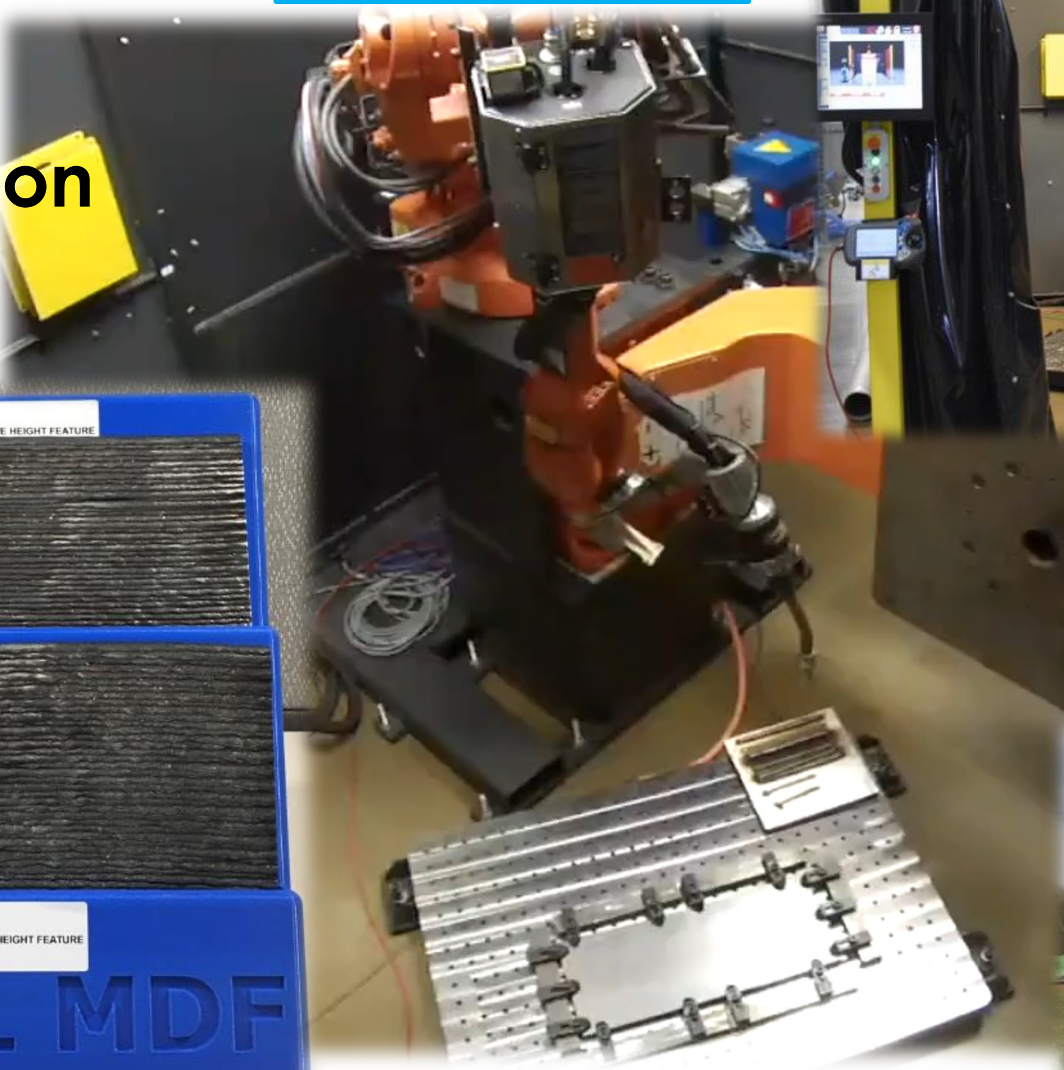
Why Wire Arc for Additive-Manufacturing ?

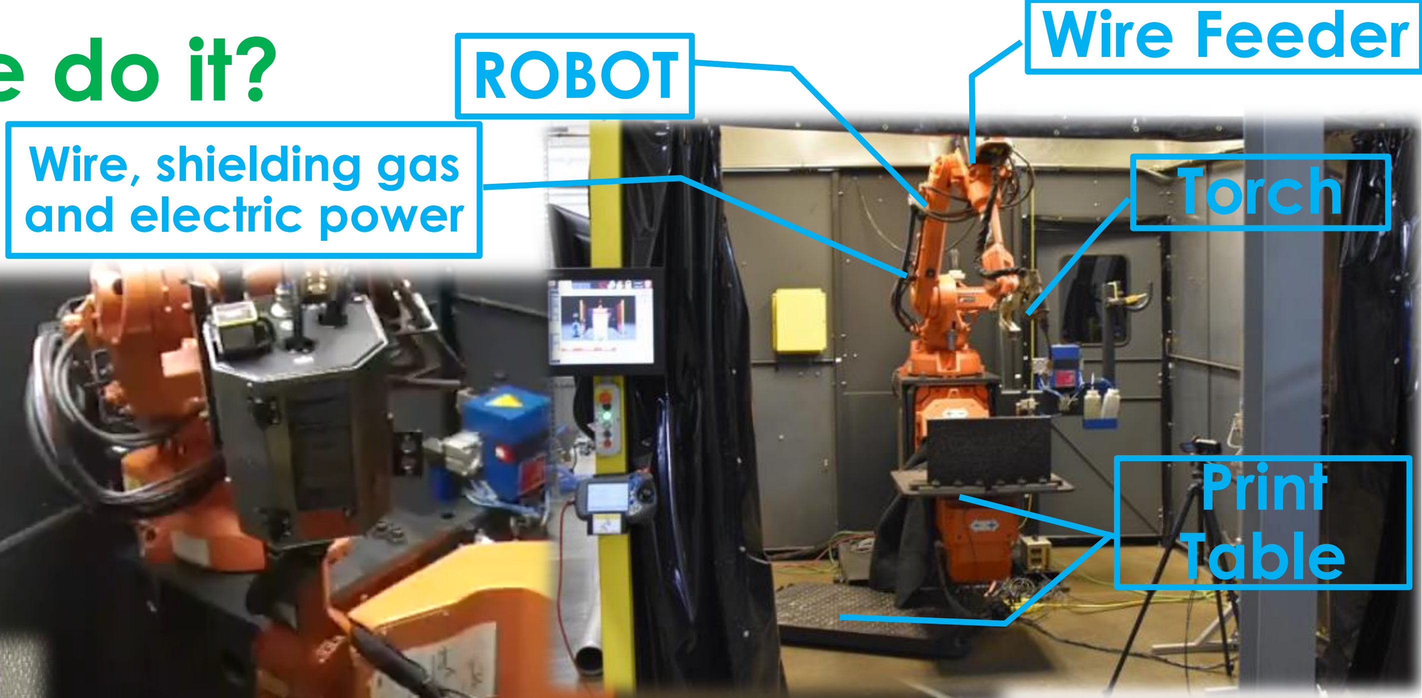
- Based in an established process, welding
- Commercial, inexpensive hardware
- Existing, low-cost feedstock (200+ types of welding wire)
- Only localized shielding needed



Wire Arc AM – How do we do it?

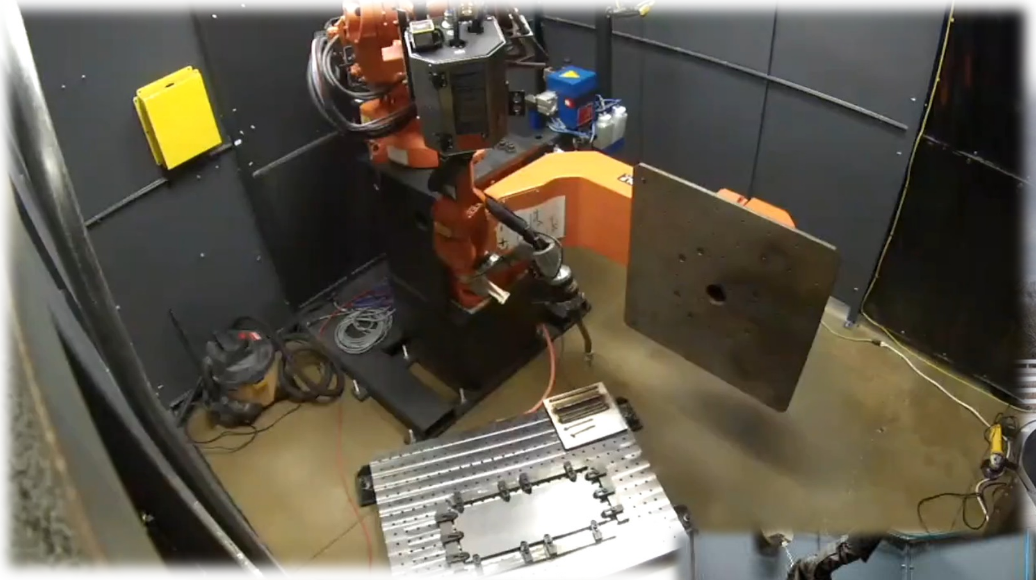
- **Robotics**
- GMAW (MIG) **AM**
- Advanced **automation**
- **Closed** loop **control**
- **5-54lb/h**
- **Milestone – Excavator arm 7' 2017**
- **Tooling!**





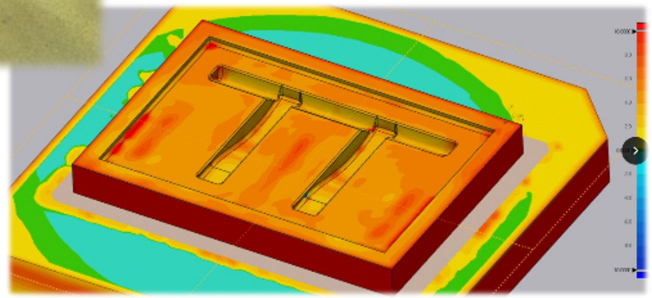
MBAAM – History
"Metal Big Area AM"

- First part Fabtech 2016
- Conexpo 2017 **3d printed excavator** live demo for 130k people
- IMTS 2018 "Die in a day"
- **Multi axis** prints
- **Multi material**
- **Tools** and **dies**









Tooling

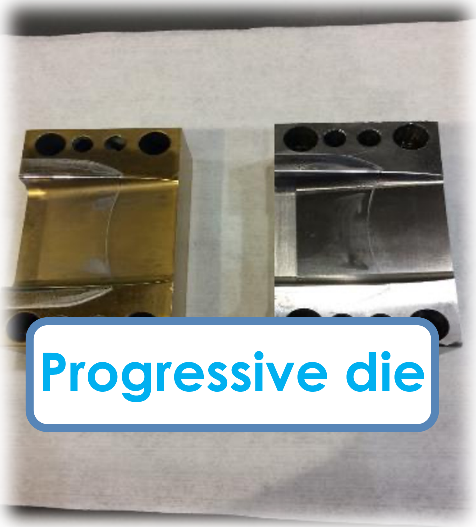
- **Compression** molding
- **Stamping** dies
- **Hot** stamping **dies**
- **Progressive** dies
- **Layup** molds
- **Die casting** molds
- Tested in production **4-80k cycles**
- Multi-material

Compression molding tool

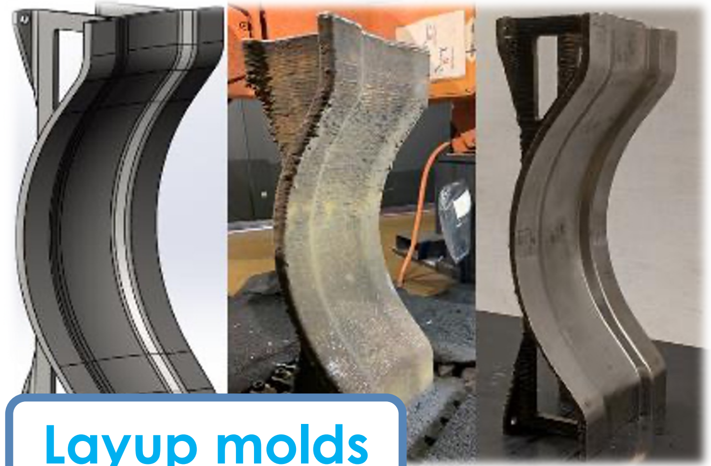
Die casting

Stamping die and parts

Mini Hot stamping die



Progressive die

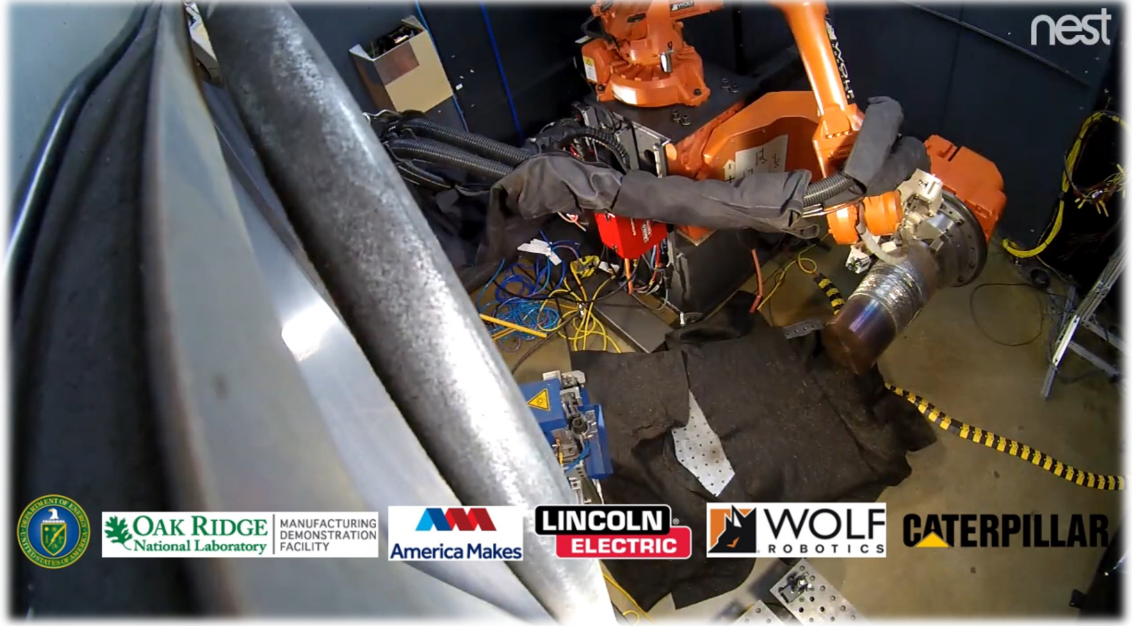


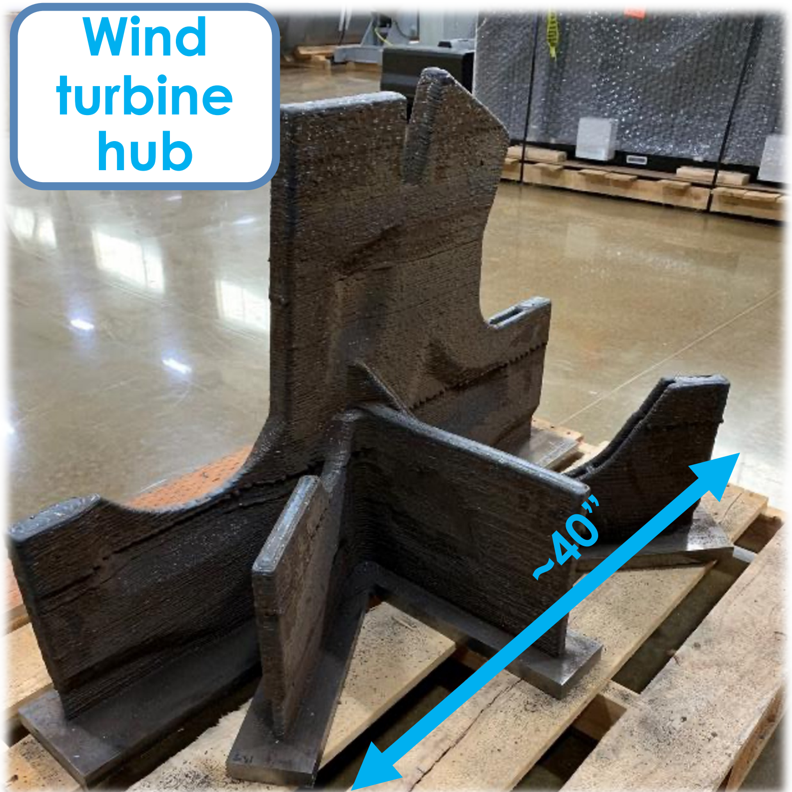
Layup molds

Printed die

Other applications

- Propellers
- Structures (wind energy)
- Nose cones



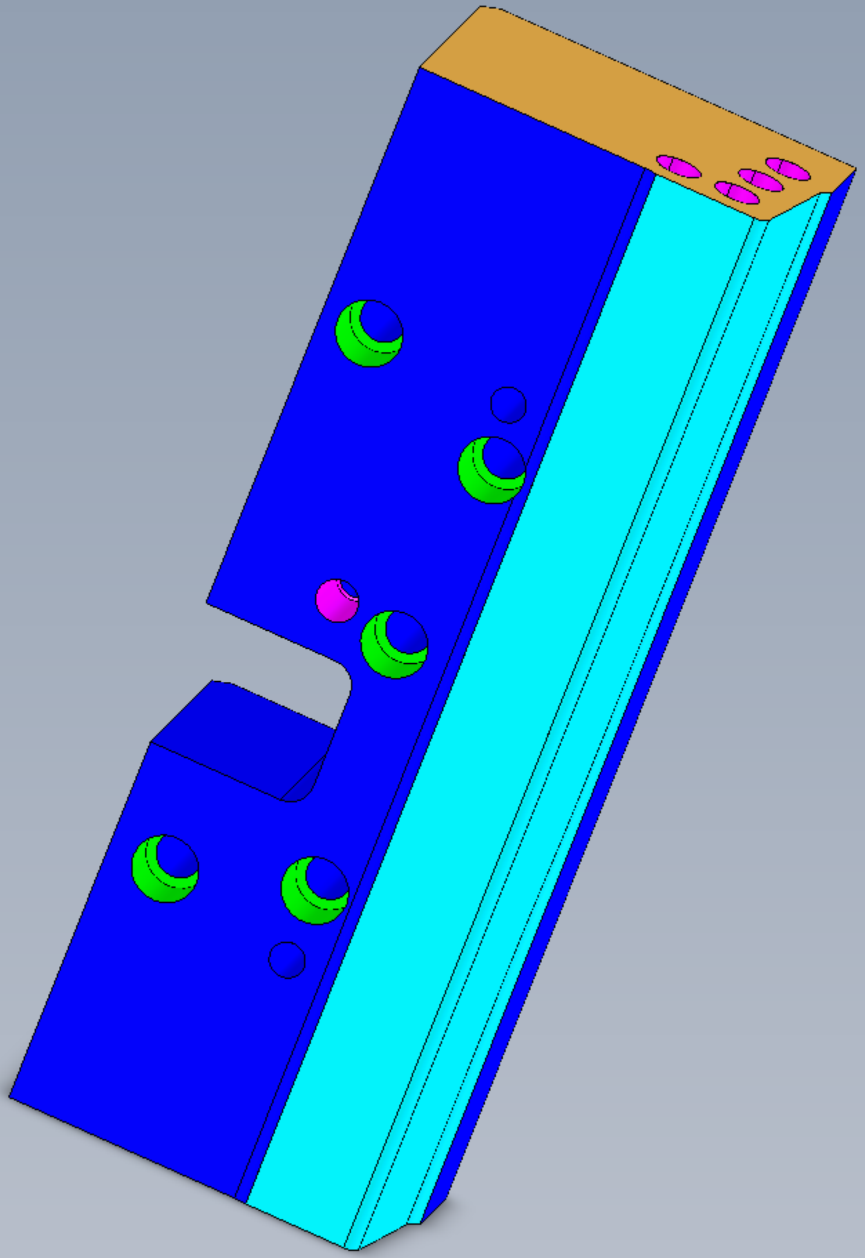


Workflow for tooling via AM

- Process development (new materials - only once)
- Mechanical properties (new materials - only once)
- **Design for AM**
- **Path planning (aka slicing)**
- **Simulation (optional)**
- **Printing**
- Machining
- Testing

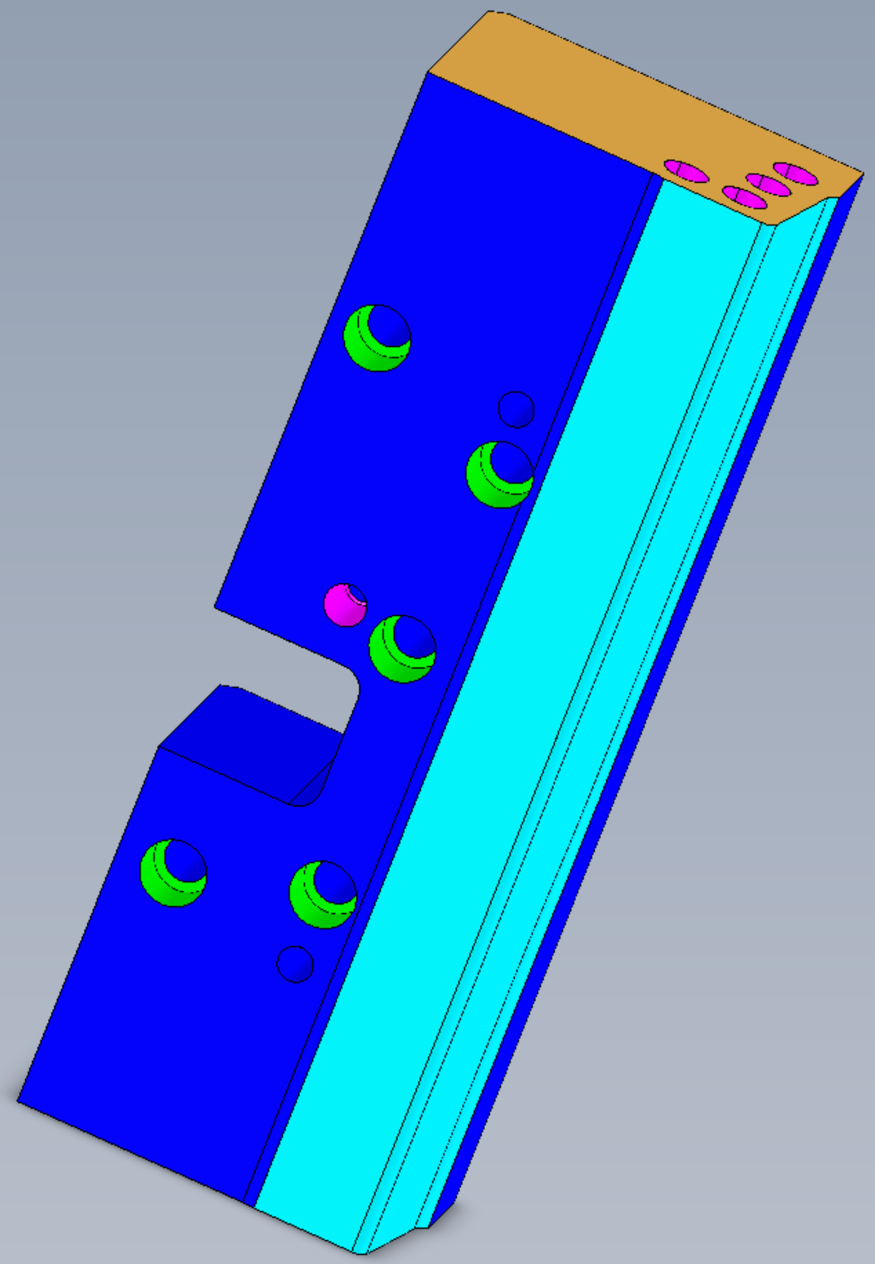
Tolling and AM Design (Elimination)

- **Feature removal**
- Small features, threads, holes
- Features not taking advantage of AM
- **Augment, not compete** with conventional ways
- **Machining** almost always **required**



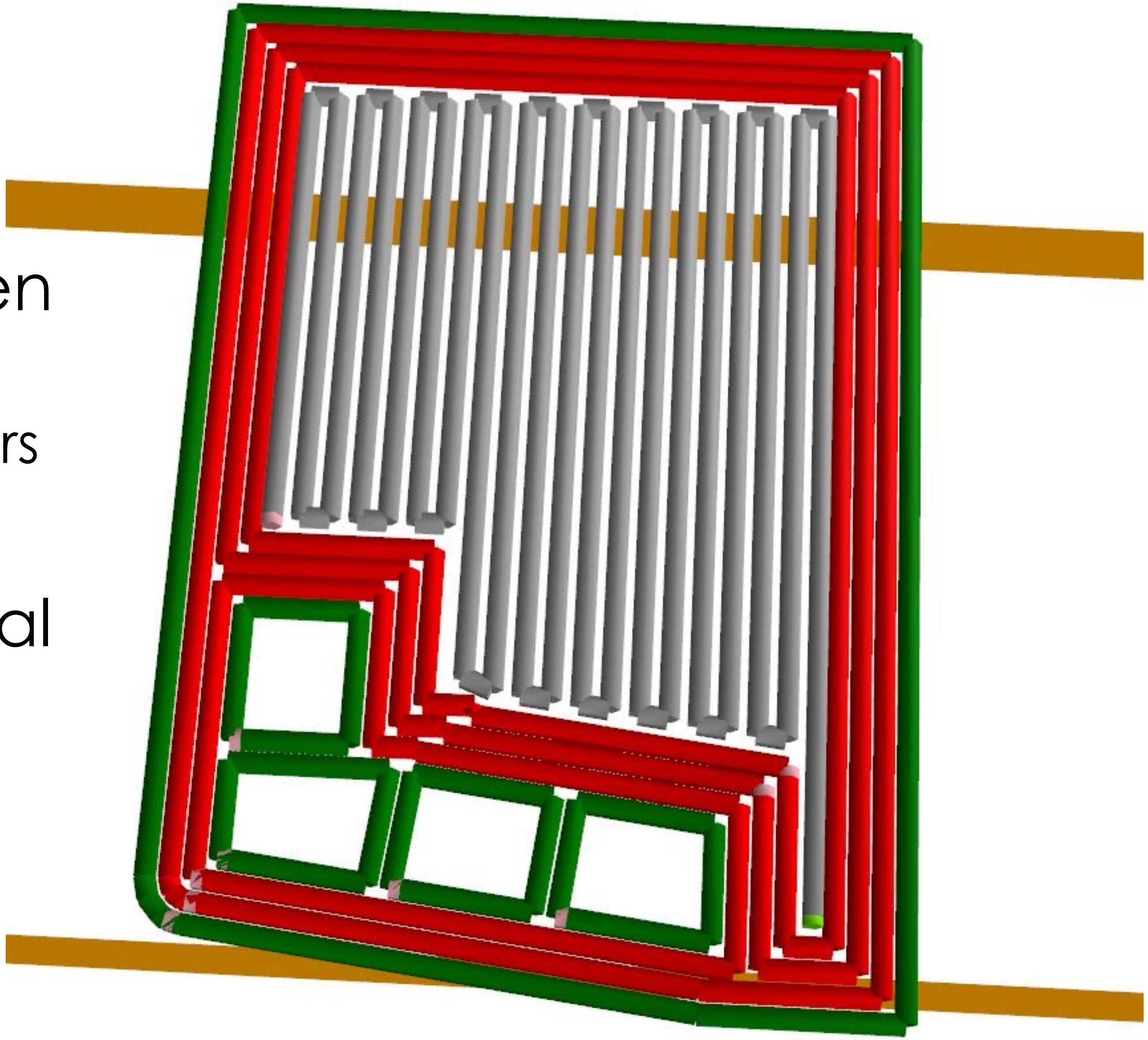
Tolling and AM Design (Focus)

- Identification of **important features**
- Role of the tool?
- Surfaces to be machined?
- Loading conditions?
- Mech properties- hardness
  - material choice



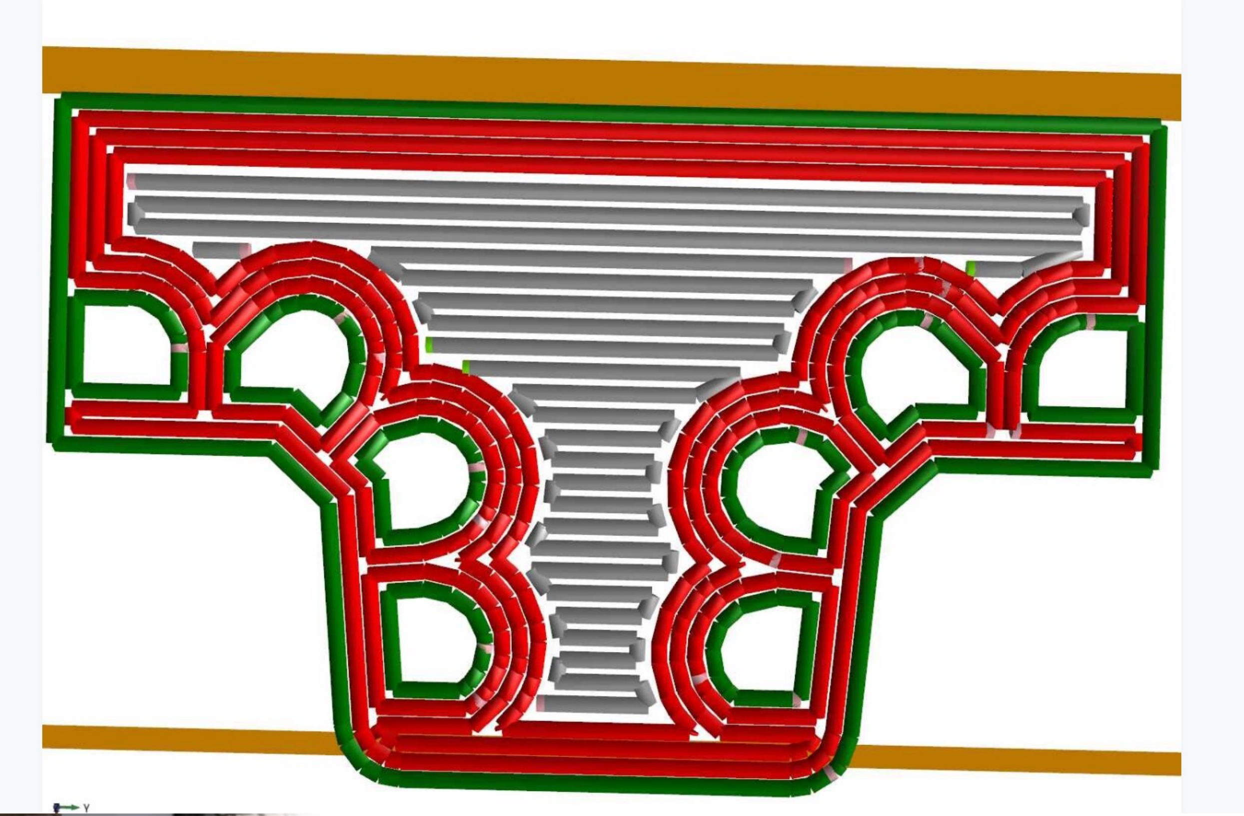
Tolling and AM - Slicing

- Divide and conquer
  - **Zone and strategies**
- Quality vs productivity – when and how
  - The **best quality** when it matters
  - The **highest speed** elsewhere
- Machining and extra material
  - Process surface roughness?
  - Pattern strategy – artefacts
- Acceptable imperfections



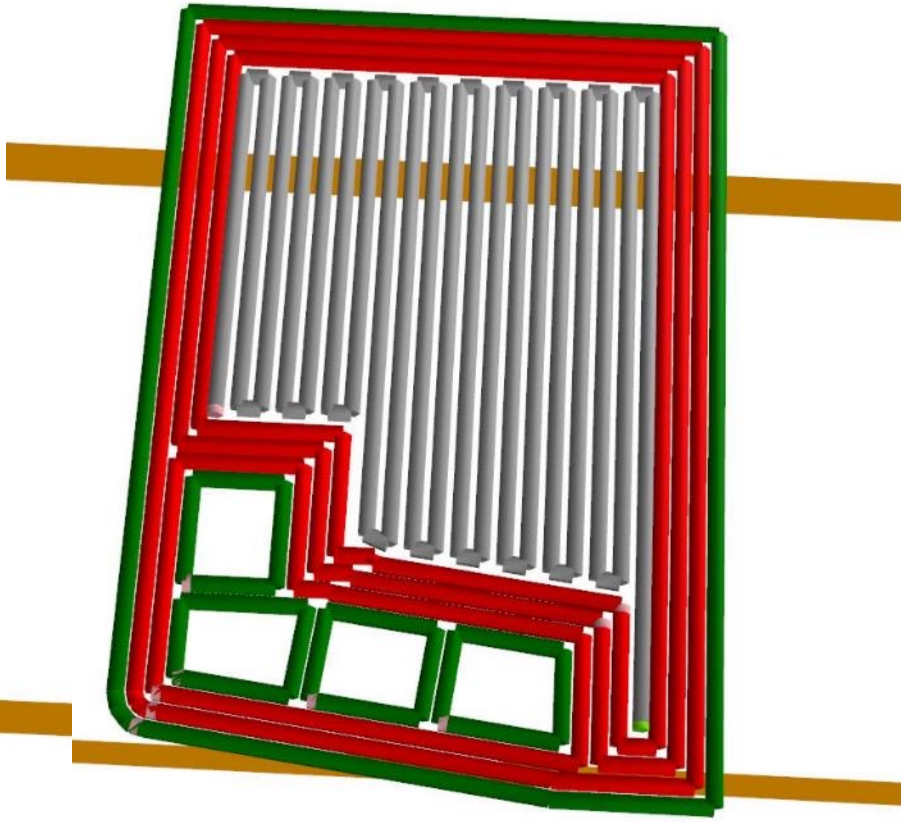
Tolling and AM – Slicing

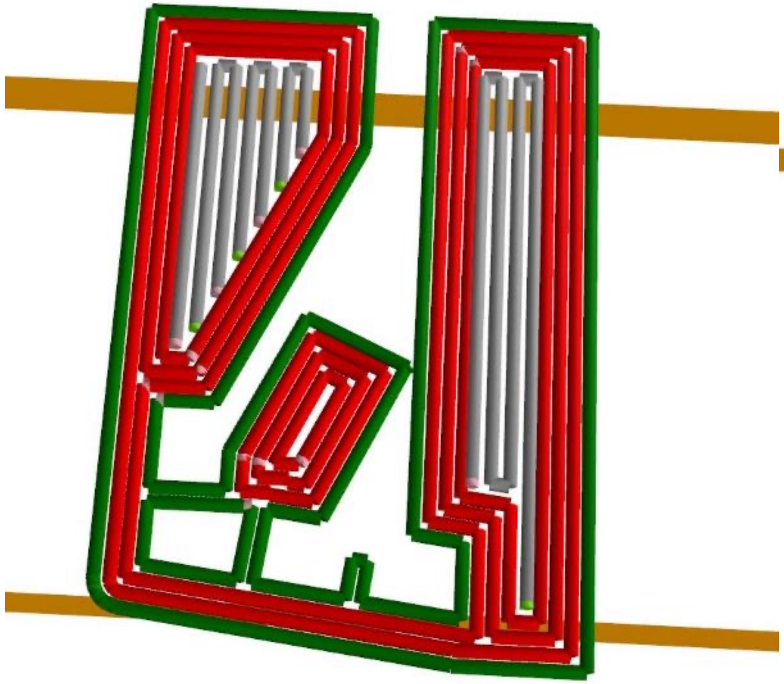
- **Digital** process
  - **Beads** and layers
  - Multiple of "**atomic**" dimensions
- Base plate
  - Included in the tool?
  - Transition zone?
- Top surface
  - Requirements
  - Different roughness
  - Extra height?



Tolling and AM – Slicing

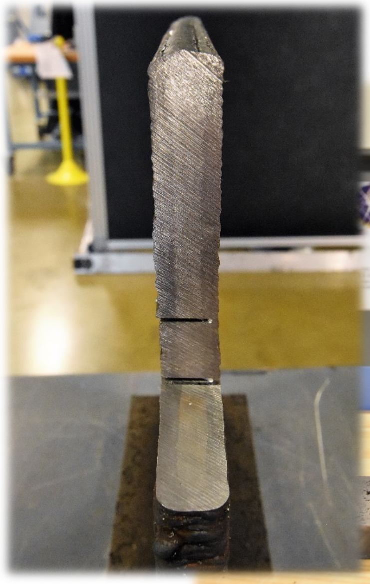
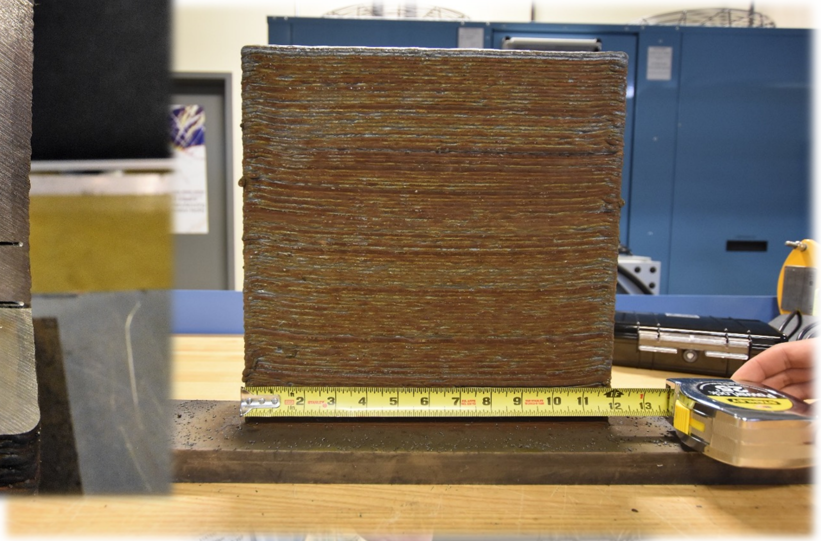
- **Hot stamping**
- **Cooling/heating channels**
  - Challenge for conventional manufacturing
  - AM free
- Shape freedom
- Flow





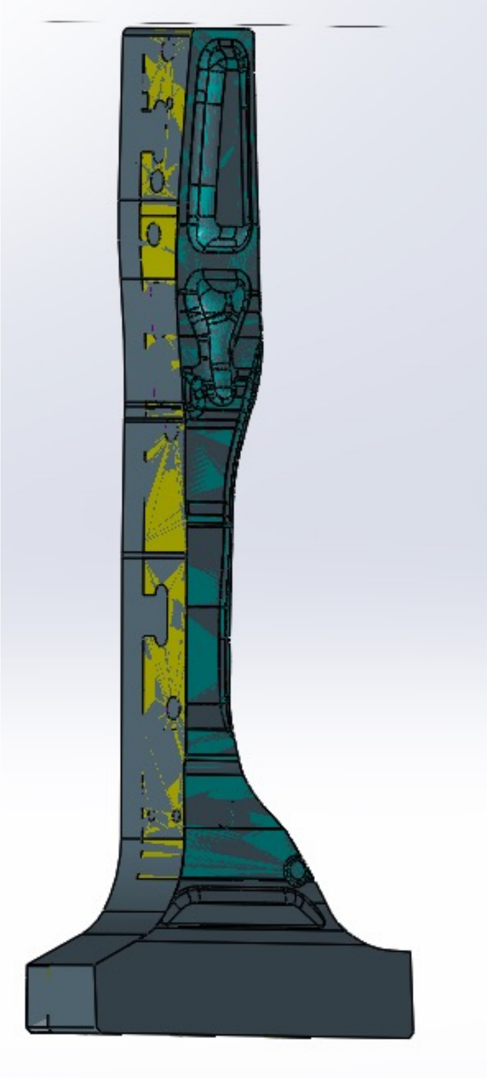
Small Hot stamping die

- First dual material wall
- Hot stamping die
- 25k cycles
- Better print – side effect

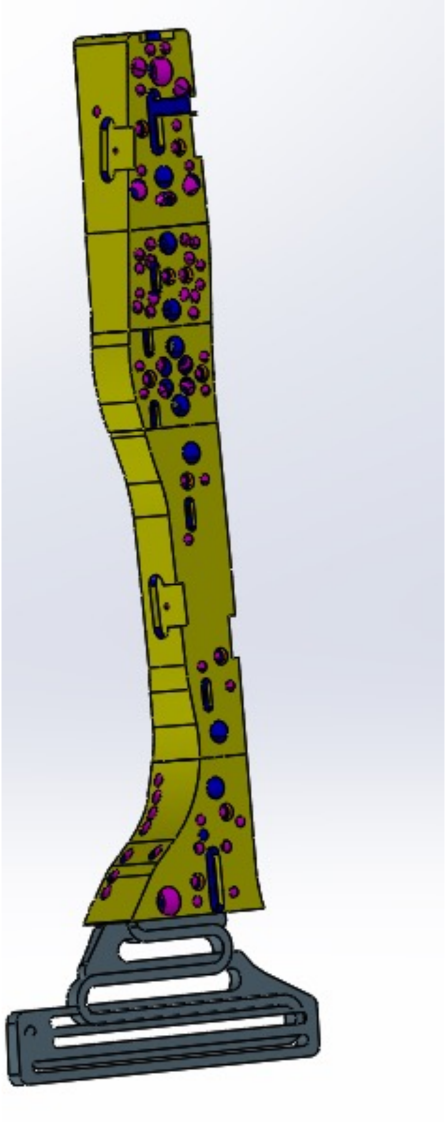





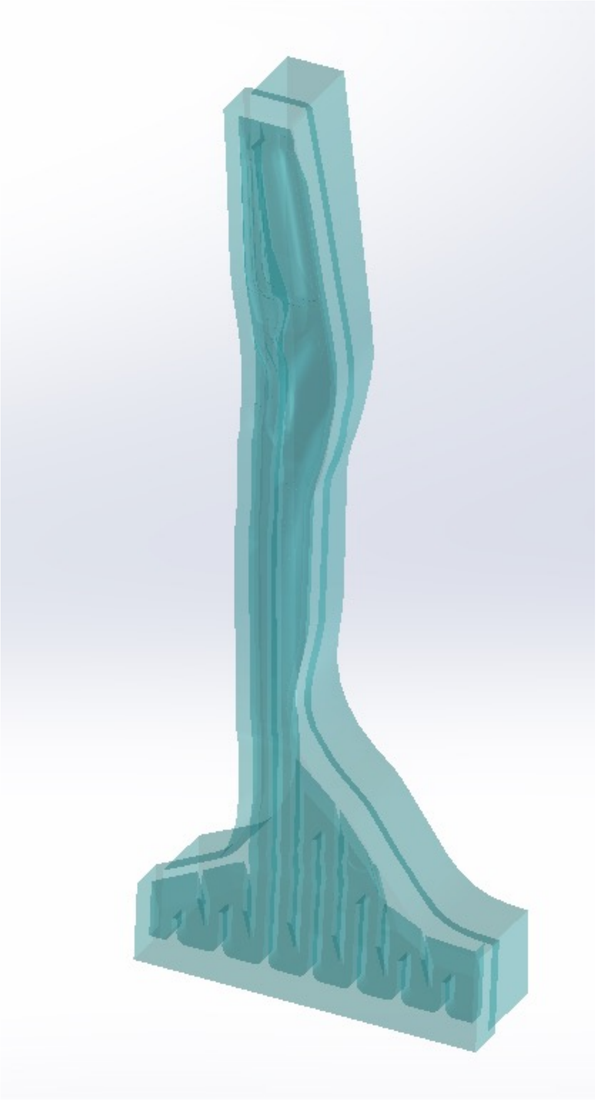
B-Pillar Hot Stamping Die



Original Model

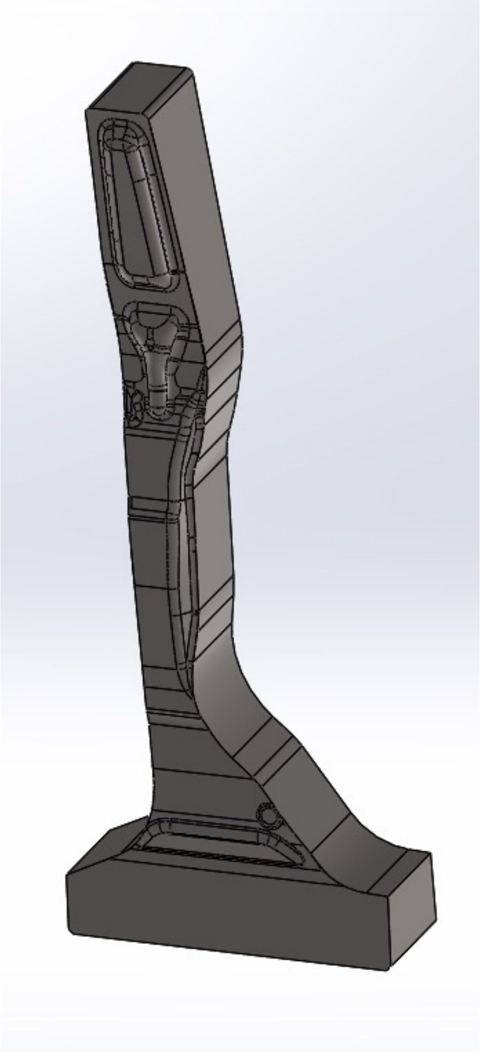


Original Model
Internal

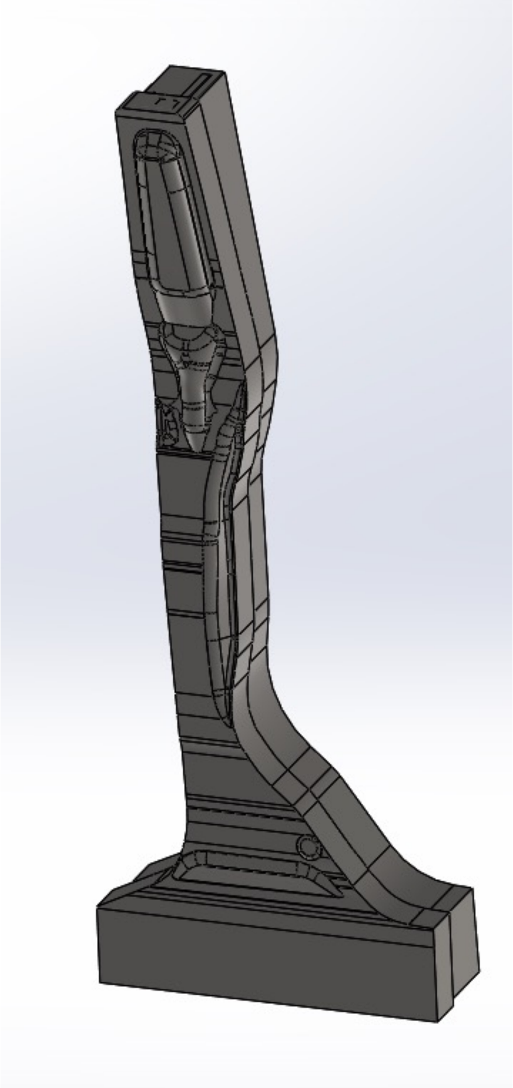


New design- monolithic

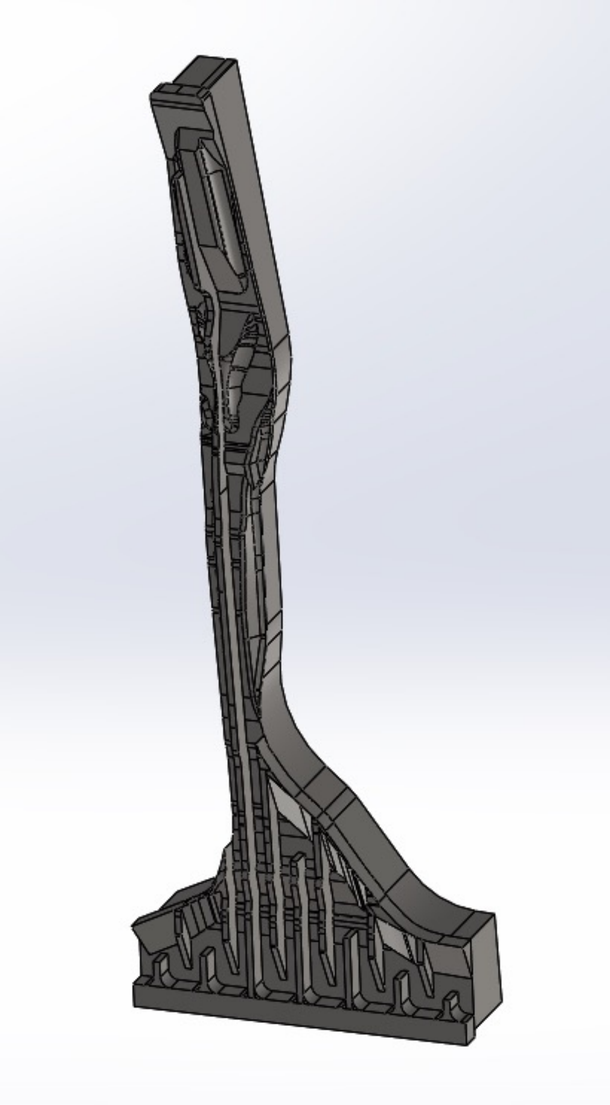
Model and Slicing Overview



Original Model



Overbuilt and redesigned
for additive (mashrooming)



Conformal cooling
channels inside part
(2 independent channels)

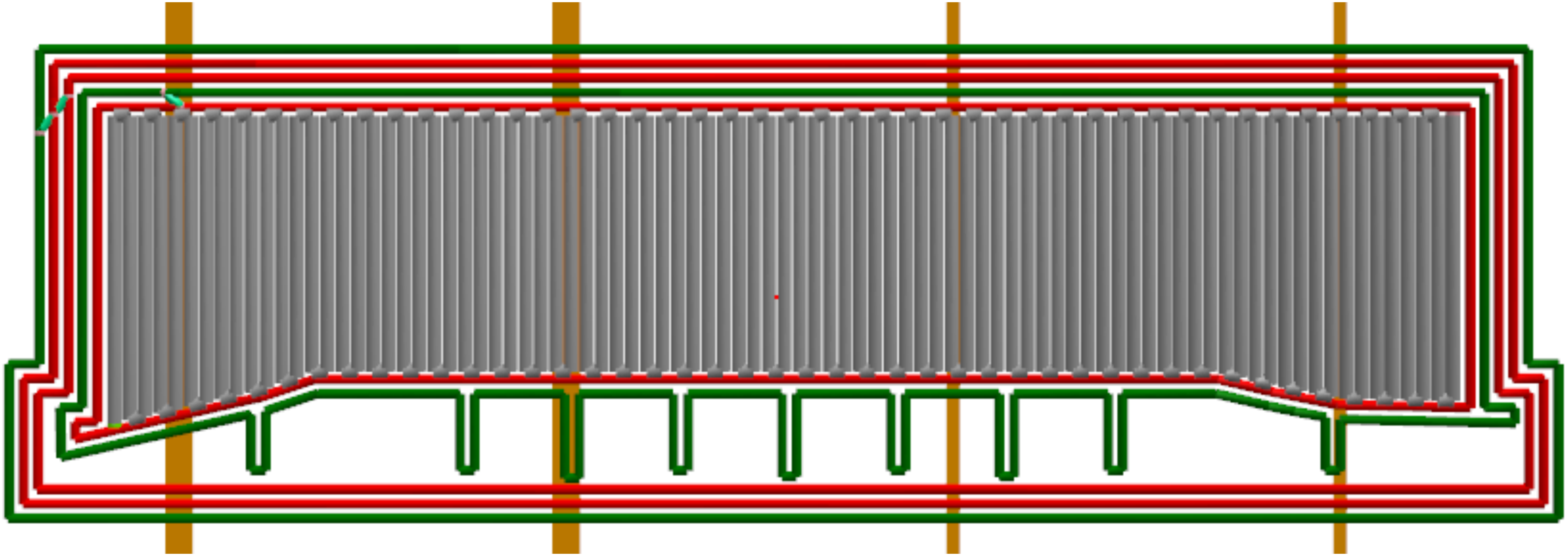
Build Plate and Base

- Dual material 410SS mild steel (ER70 S6)

Basic rules

- 3mm to 5mm overbuild on tooling surface as-designed
- Channel-to-surface may be as thin as 10mm post-machining
- Back surface is nominal
- Sides are 3mm overbuilt, then “mushroomed” inward

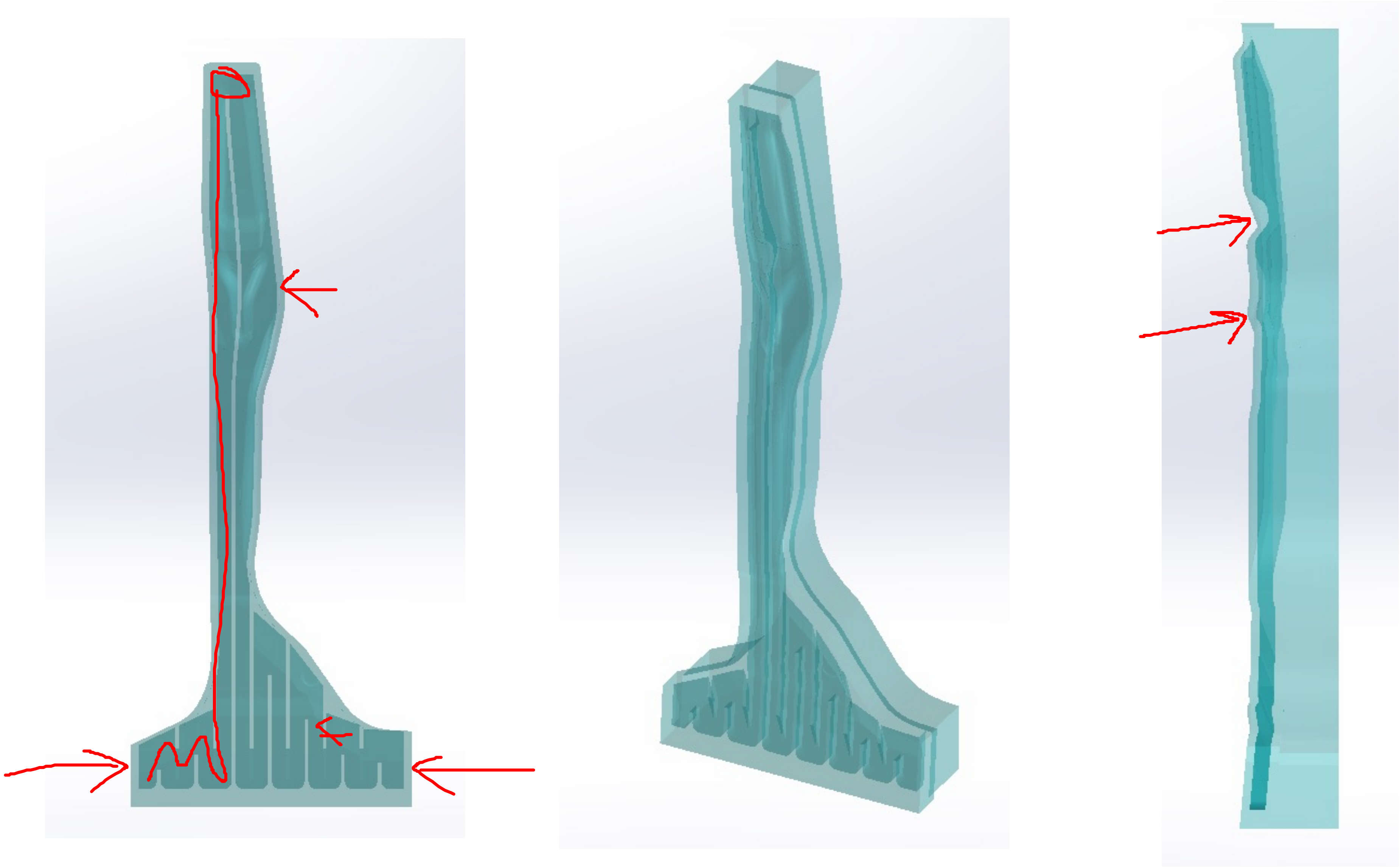
Manifold creation



- Sliced as two separate bodies: Outer body (outermost 3 loops) and inner body (grey infill and surrounding 2 loops)

- 3 consolidated weld beads: infill, inner body, and outer body

Fully modeled HSD



Two independent cooling channels: Design flexibility, path flexibility, closely controlled distance-to-surface

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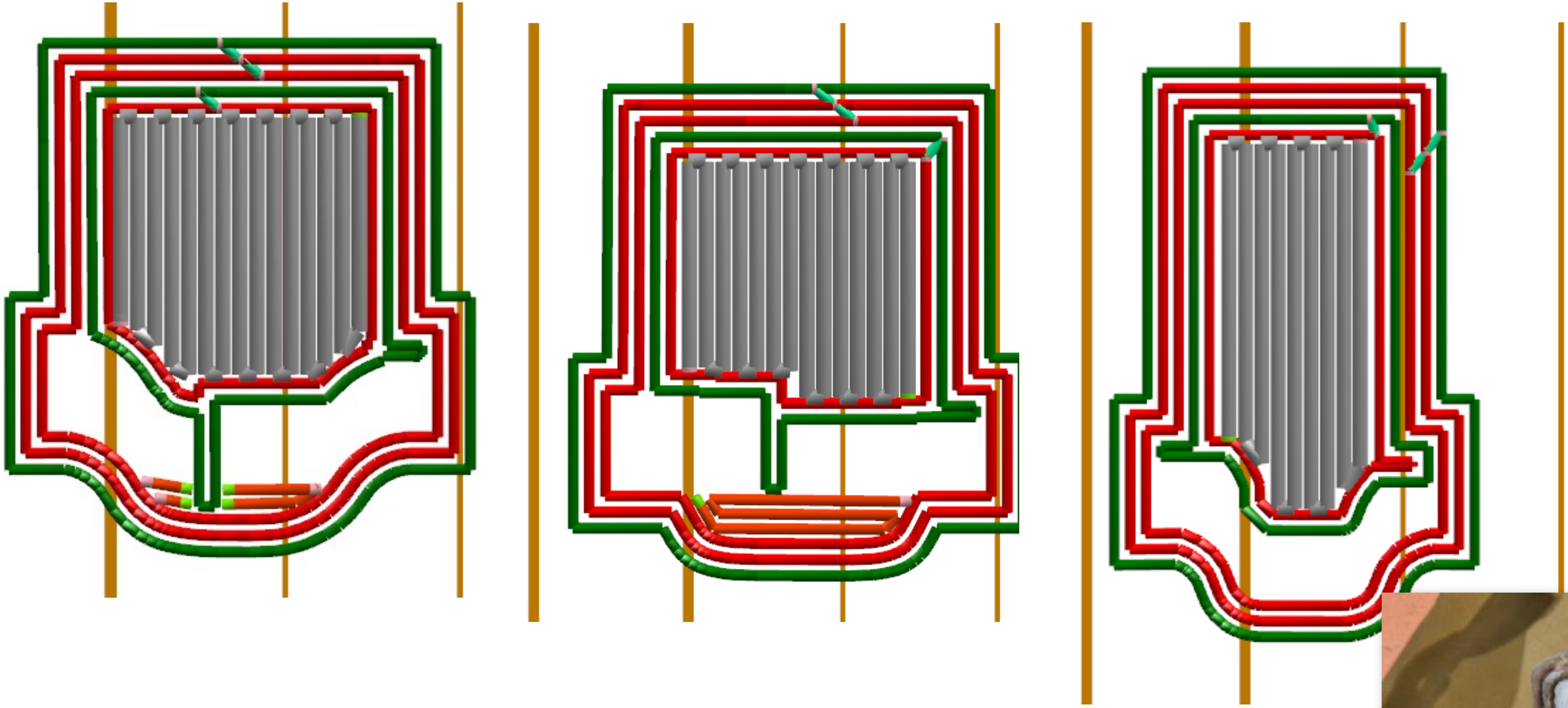
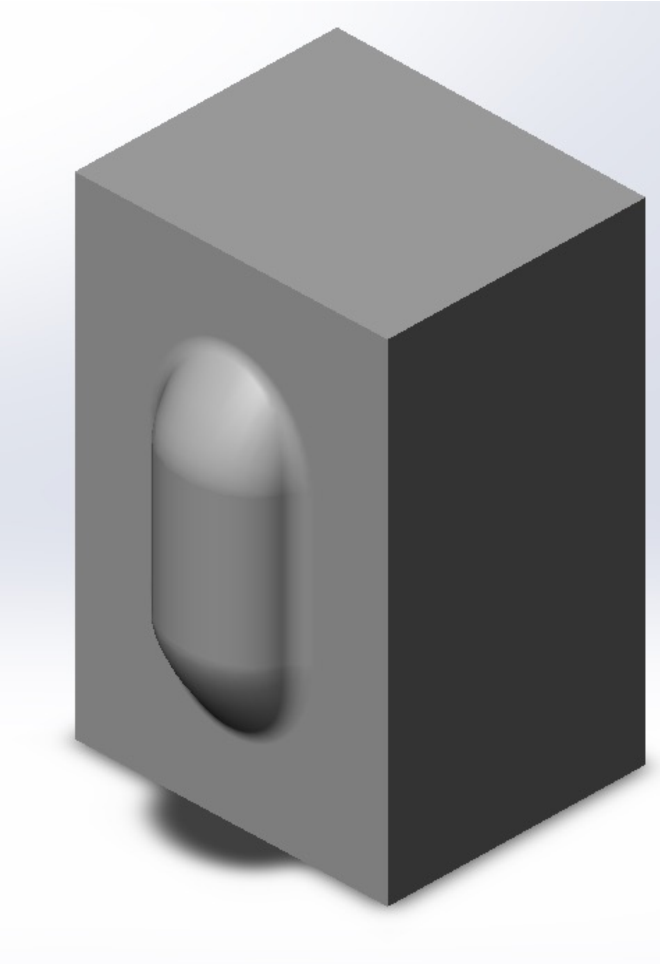
Conformal cooling channel design and slicing

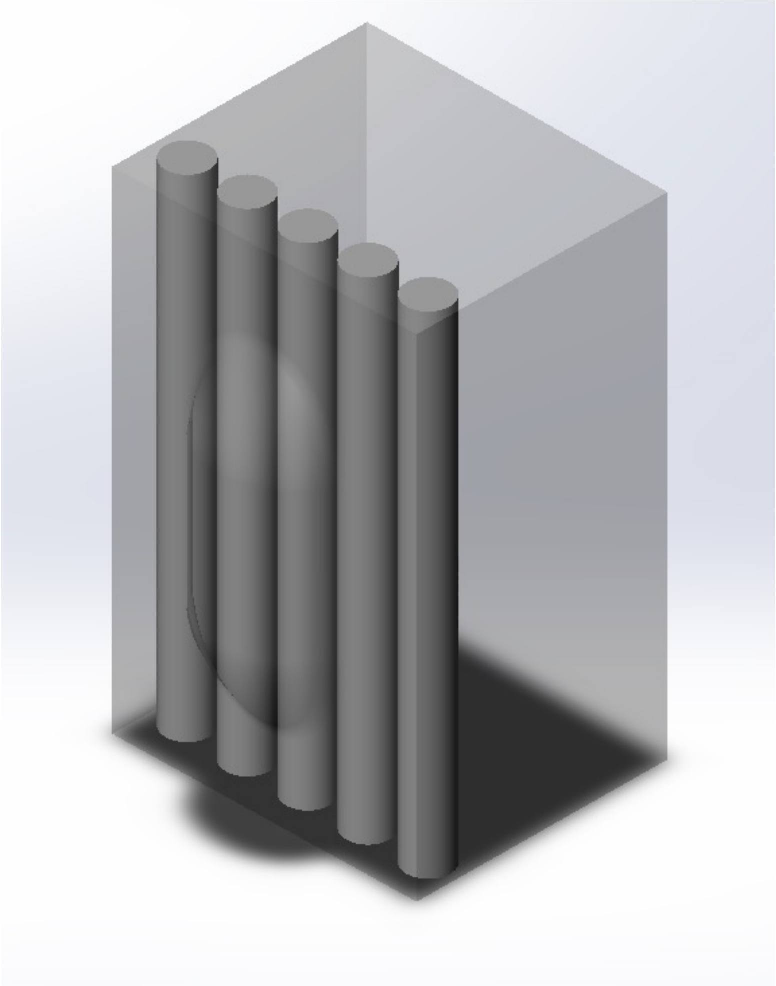


- Overhangs on critical features handled by torch angle compensation
  - Torch angle orients at 20˚ from vertical to “push” material into existing

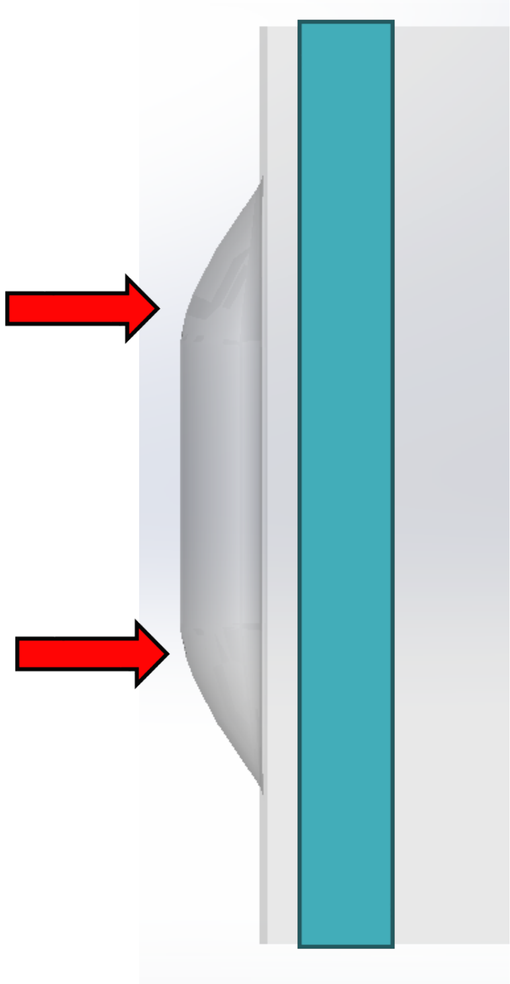
Classic approach: Complex geometries



Complex feature geometry

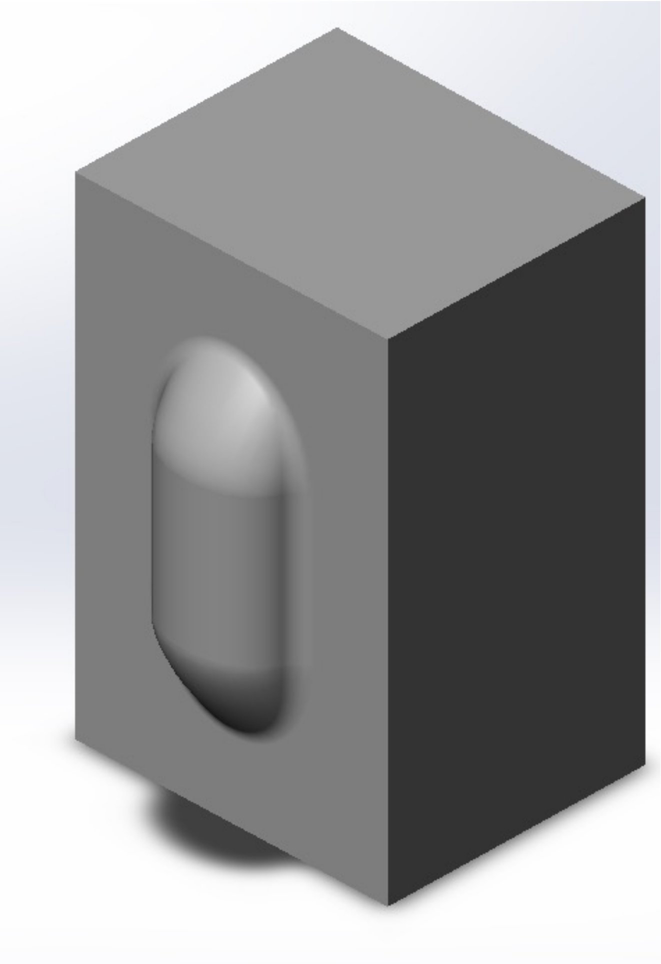


Drilled cooling channel network (traditional)

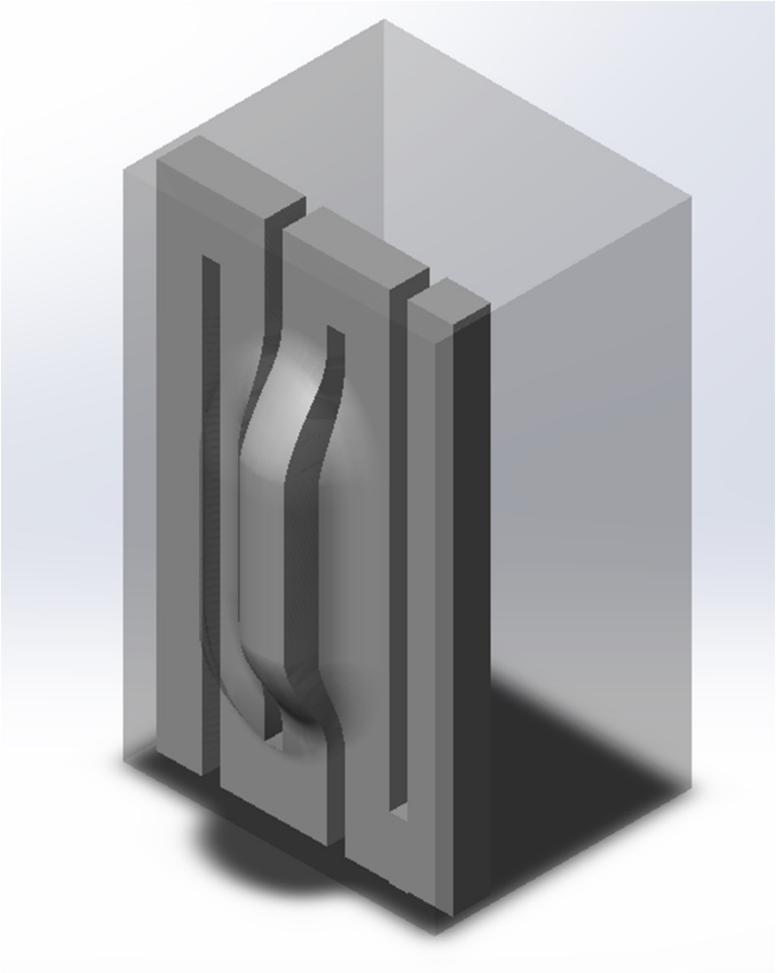


Lack of cooling at complex features

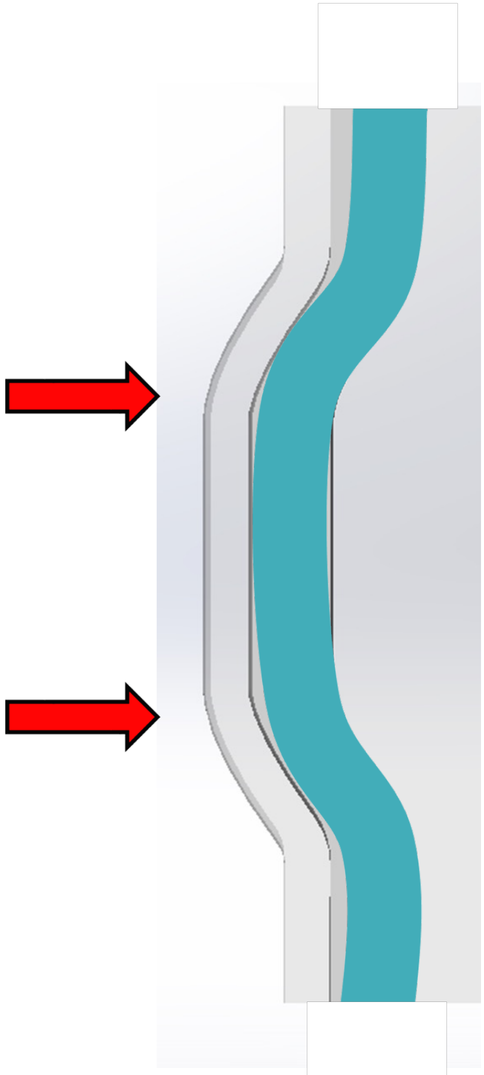
Our AM approach: Complex geometries



Complex feature geometry



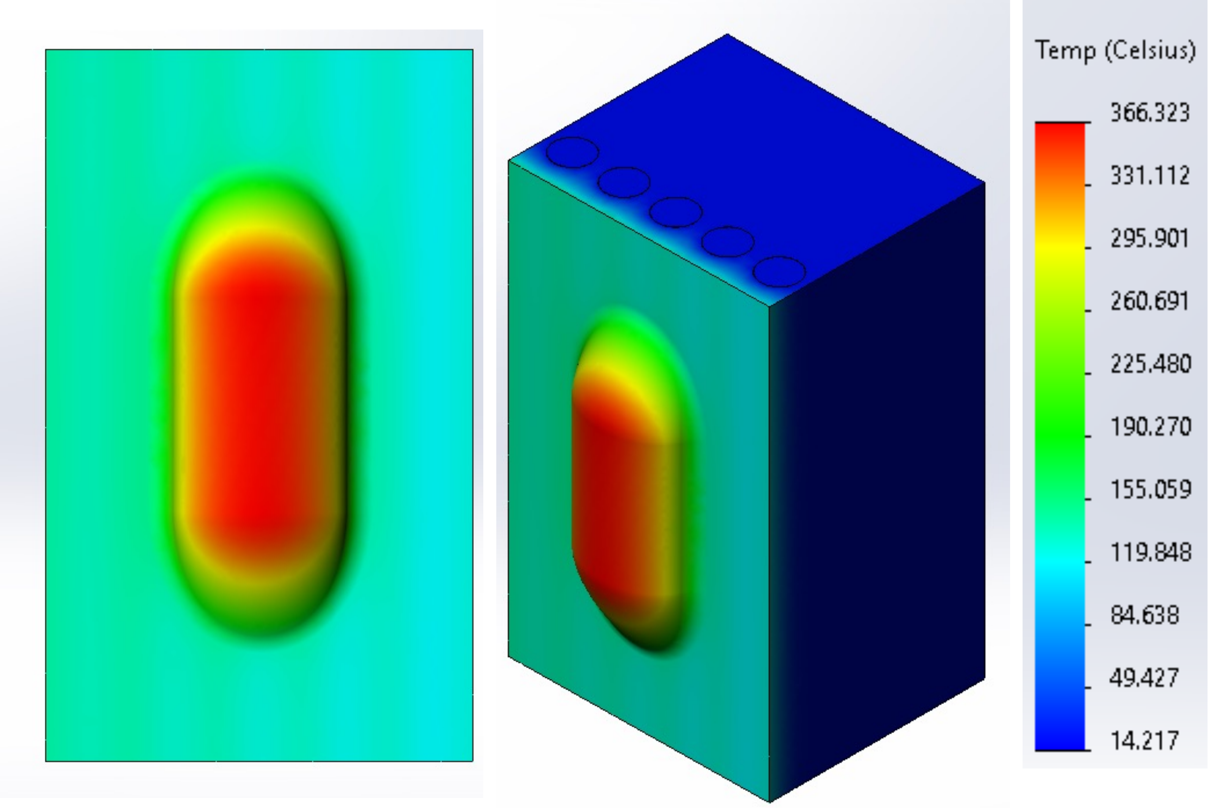
WAAM cooling channels



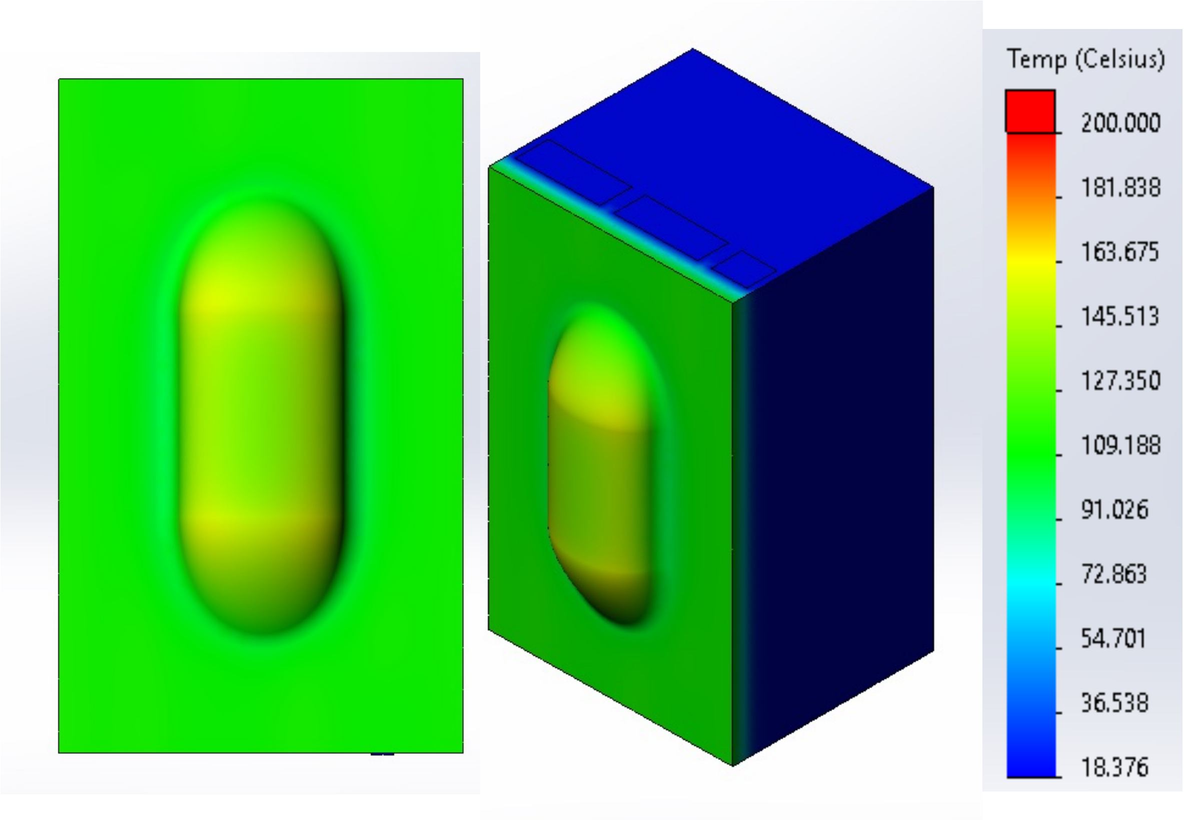
Improved cooling at tooling surface

Cooling improvements

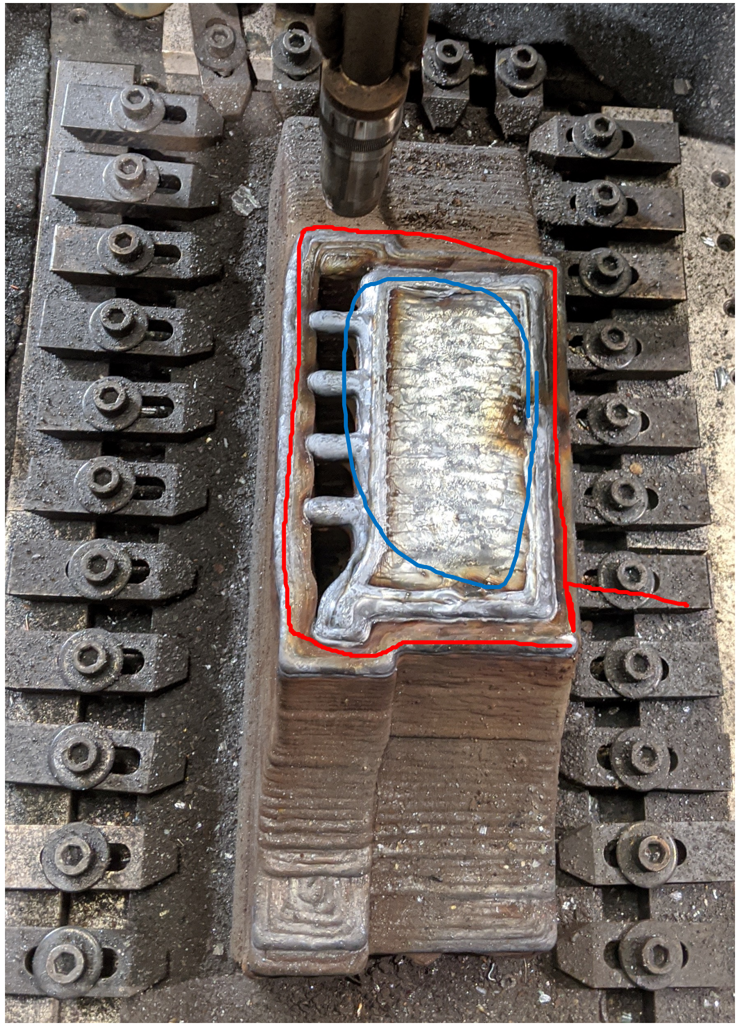
Drilled Channels



Conformal AM Channels



HSD Printing

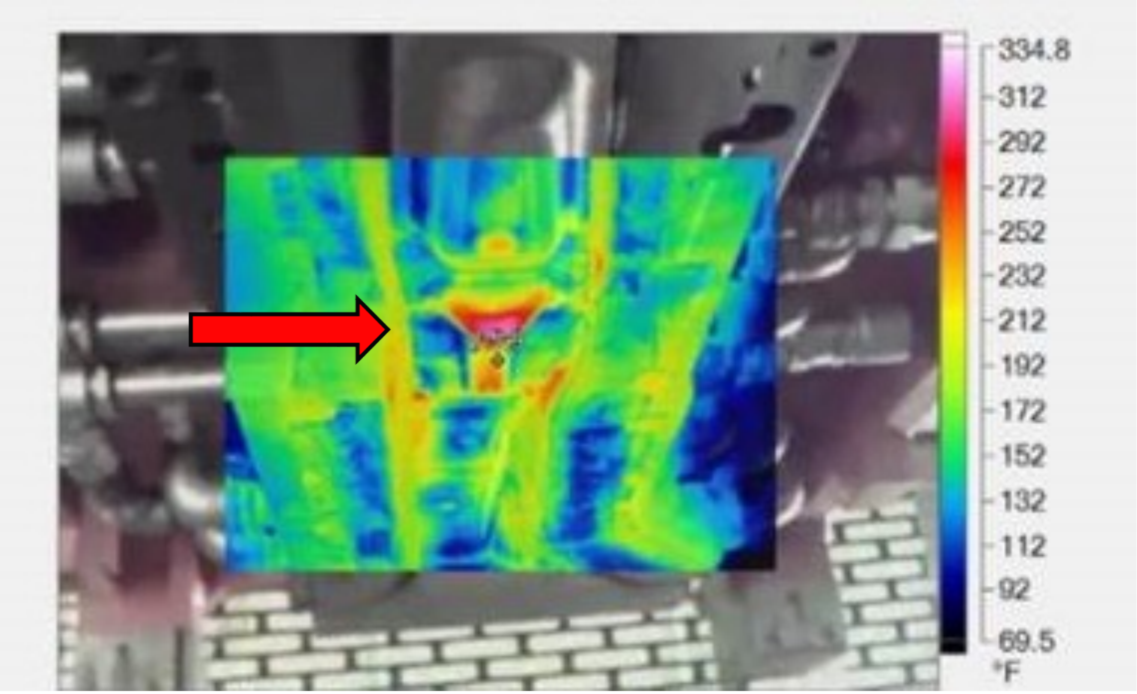


During printing

Printing complete

Tooling surface machined

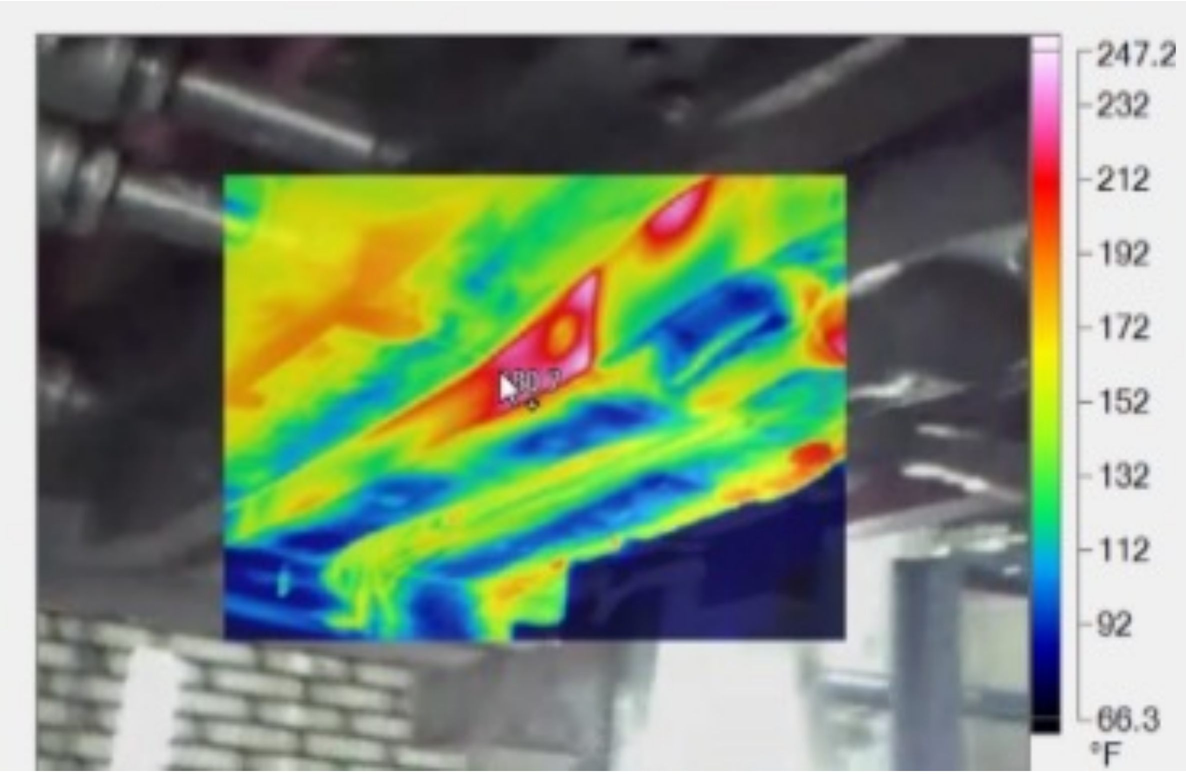
Results on an AM workpiece



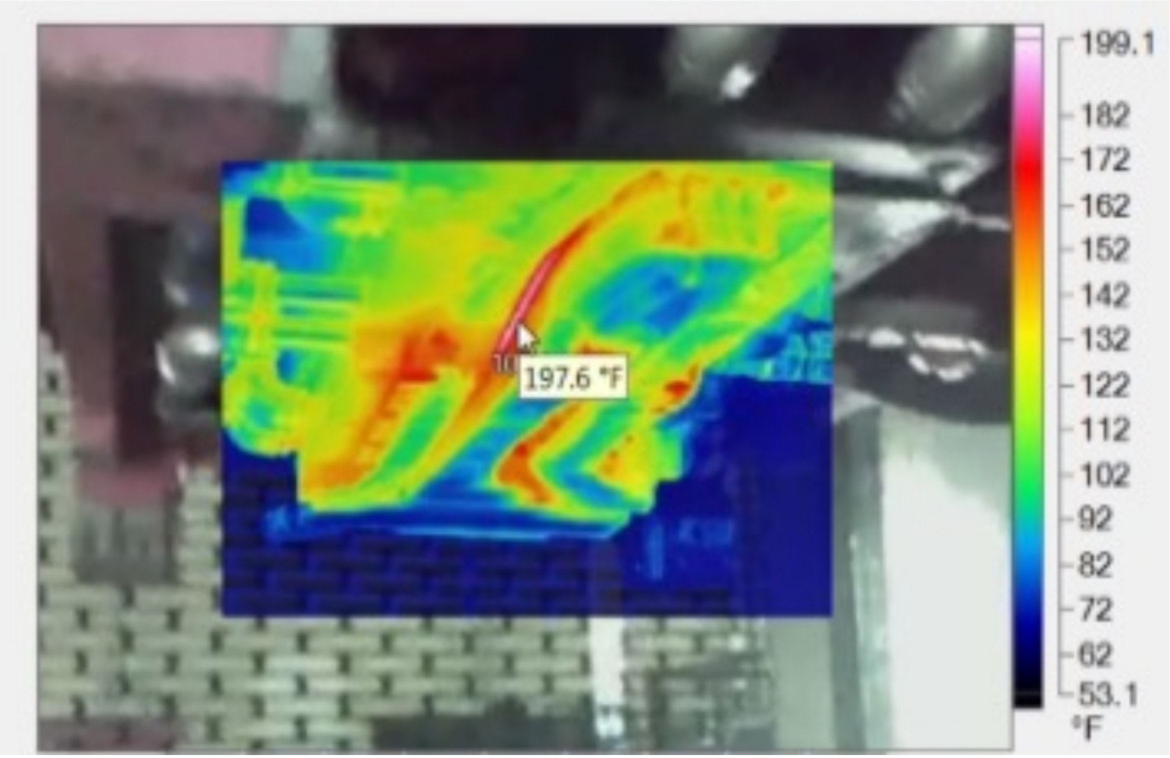
Original detail: 332 degrees F at 25 seconds

Printed detail: 266 degrees F at 25 seconds (same area)

Results on an AM workpiece



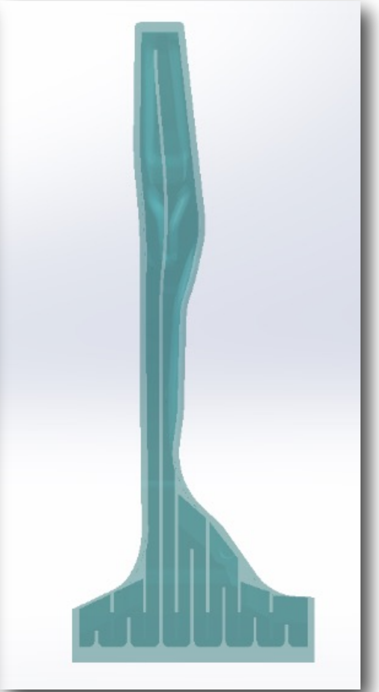
Original detail: 245 degrees F at 45 seconds



Printed detail: 197 degrees F at 45 seconds (same area)

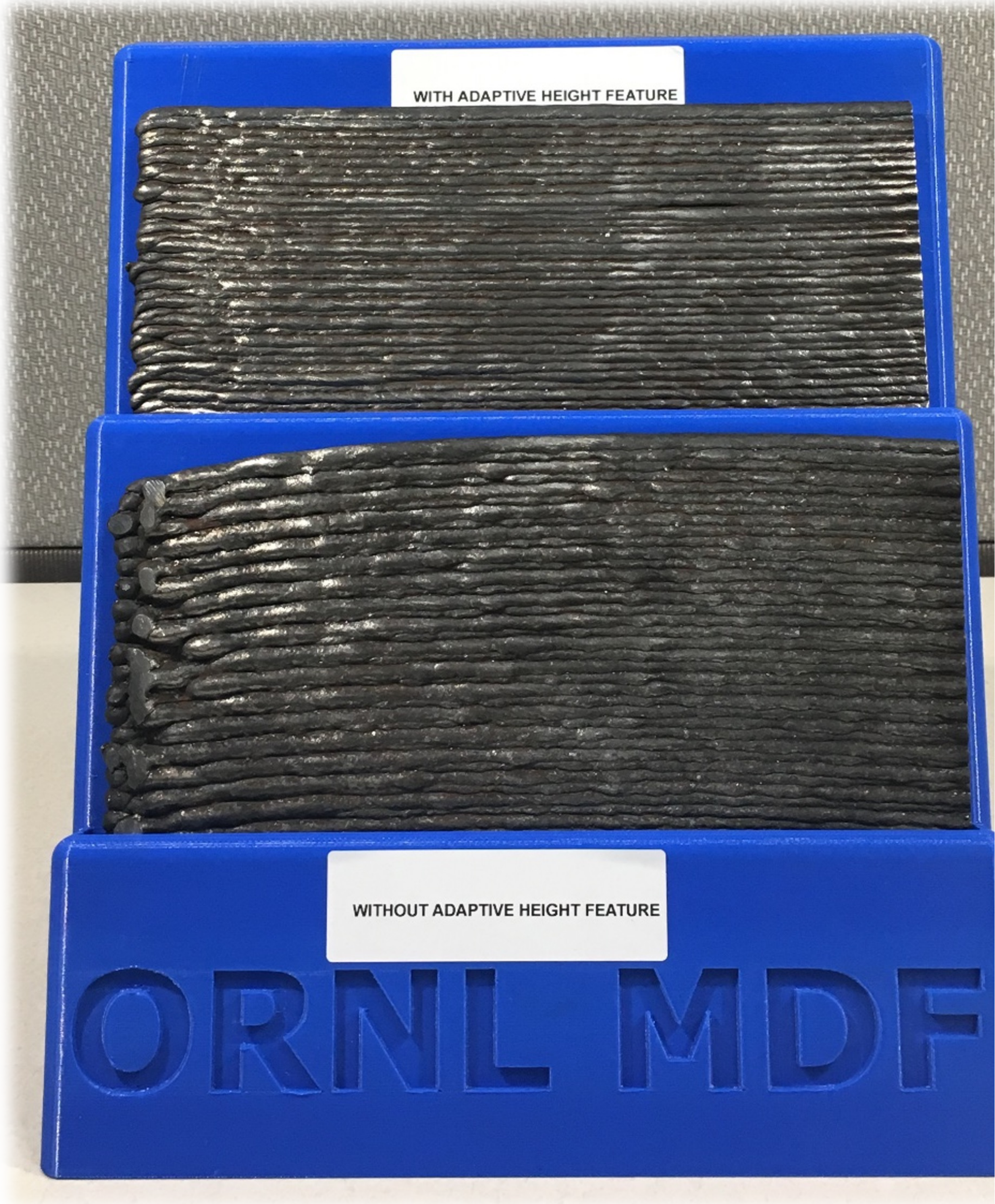
Full-scale B-pillar Hot Stamping Die

- ~400lb, 5ft tall, 3 days of printing
- Multi-material
  - 410SS outside
  - mild steel core
- Internal conformal cooling channels with manifolds
- Improved
  - lead time and cost -20 to 8 days
  - part cooling time and uniformity 20 % improvement in cooling



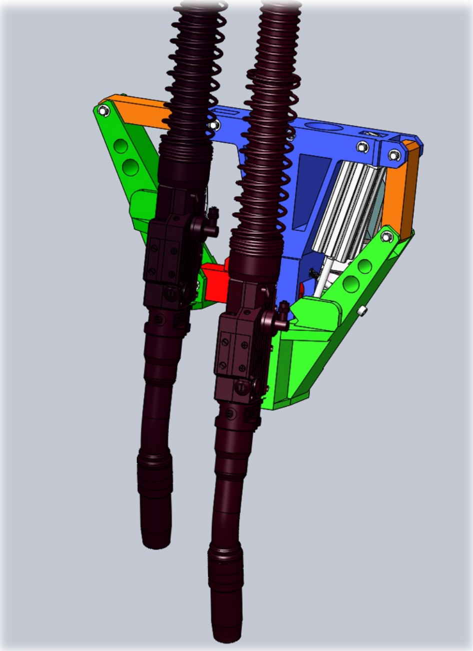
Research System Capabilities

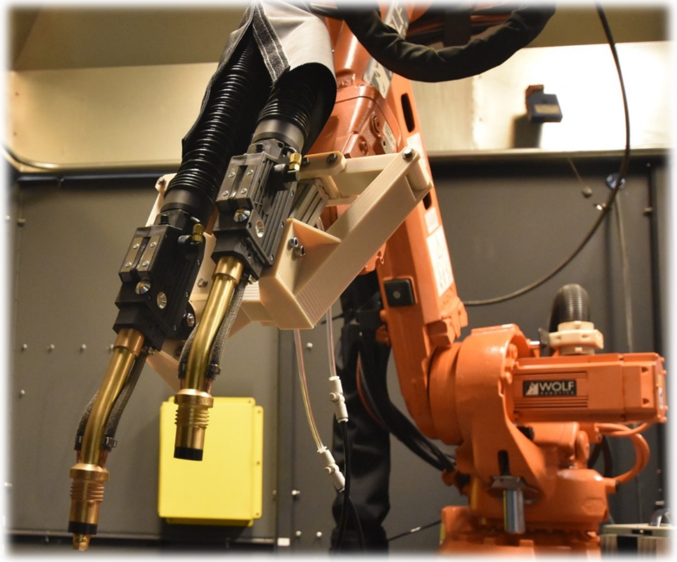
- Hardware
  - 6 DOF IRB 2600/4600 ABB arm + 2 DOF Positioner
  - GMAW (MIG) PowerWave S450 Welder
- Build workspace
  - Build table (4x3 x 8/10') stationary (**upgradable**),Positioner (3x3x5') (**upgradable**)
- Closed Loop control x3
  - Part sensing
  - Surface following
  - **Height control**
- Sensing
  - Temperature (IR, thermocouples)
  - Welding conditions
  - System variables
  - system status logging
- **Multi-material**
- **Near net** shape
- **Low cost** feedstock

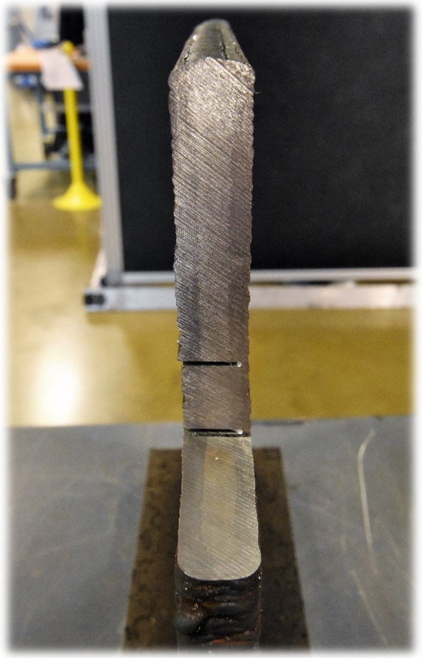


Capabilities – Deposition rates and path generation

- **True 3D printing** – computer generated path
  - Custom ORNL slicer and partner's slicer
- Flat slicing **OR 8+** axes coordinated motion (**real 3D**)
- 5-54lb/h
- Multi-material deposition - **computer generated**, within the same part!

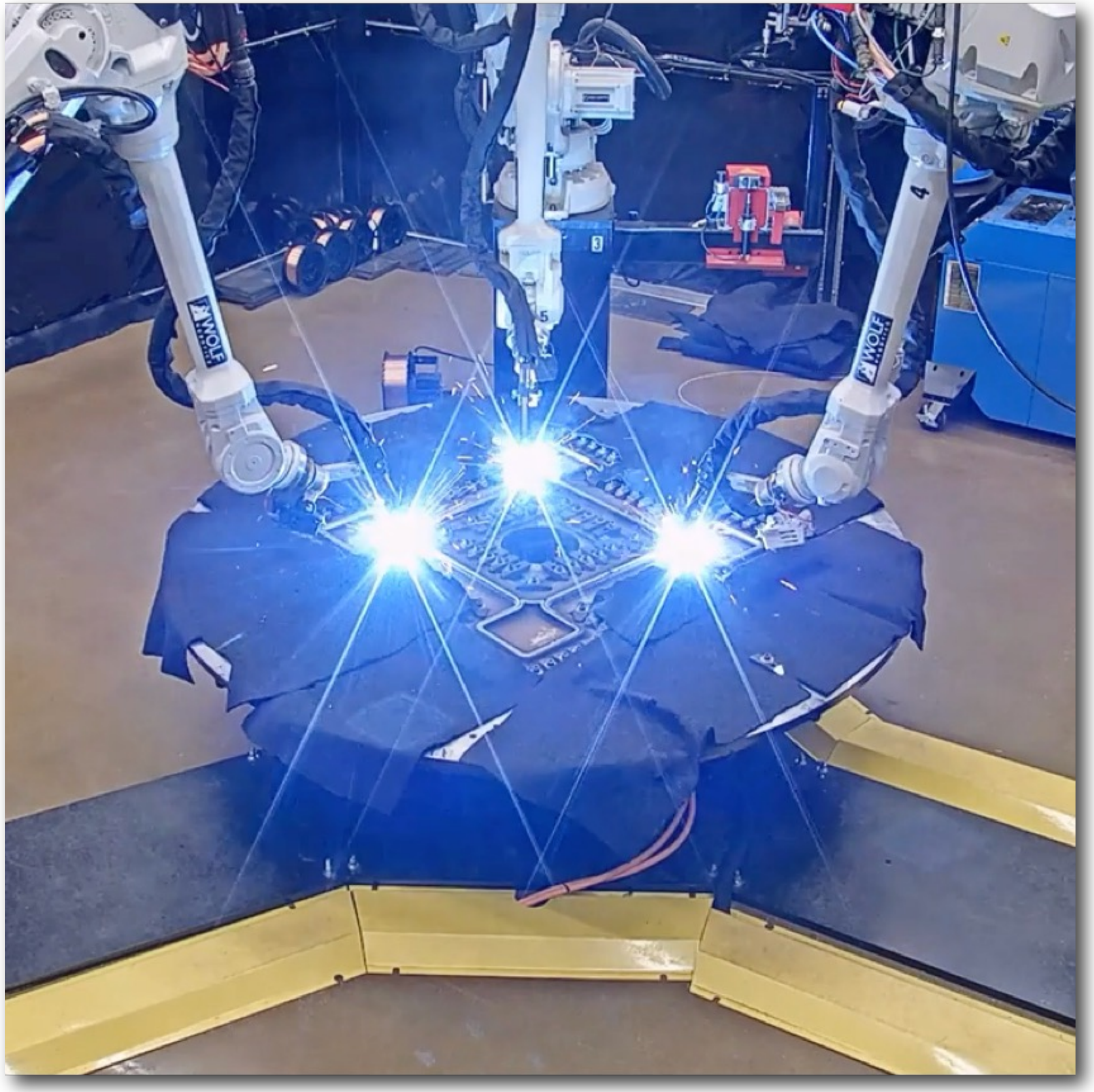




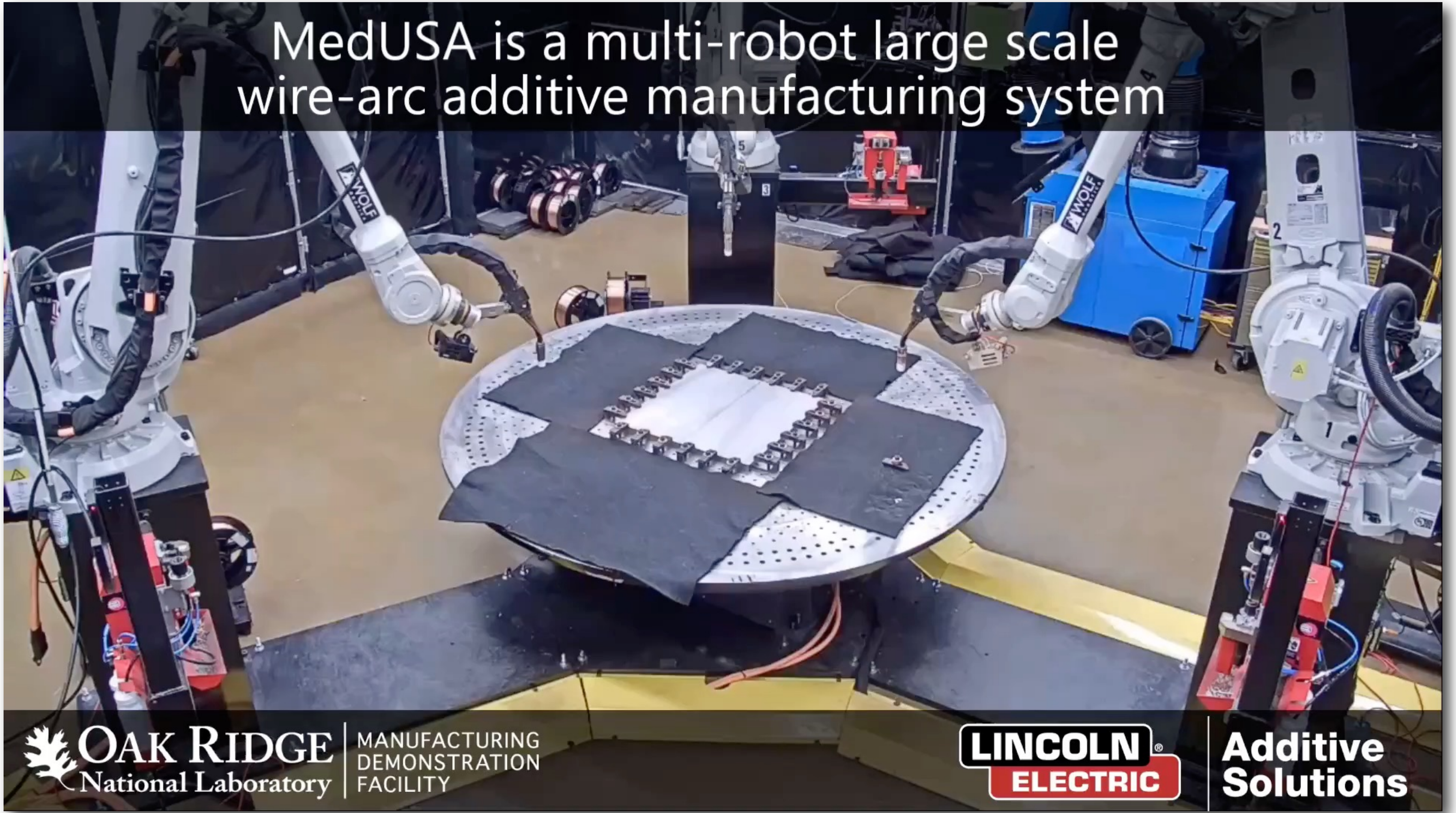


MedUSA – Using Multiple Robots to Increase Deposition Rates

- Coordinated motion with dynamic bead assignment
- Current max 54lb/h (18lb/h x 3)

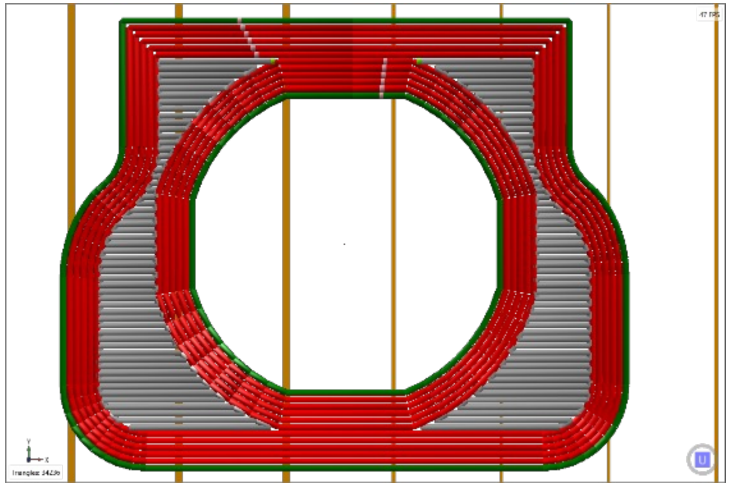


Dynamic Bead Assignment



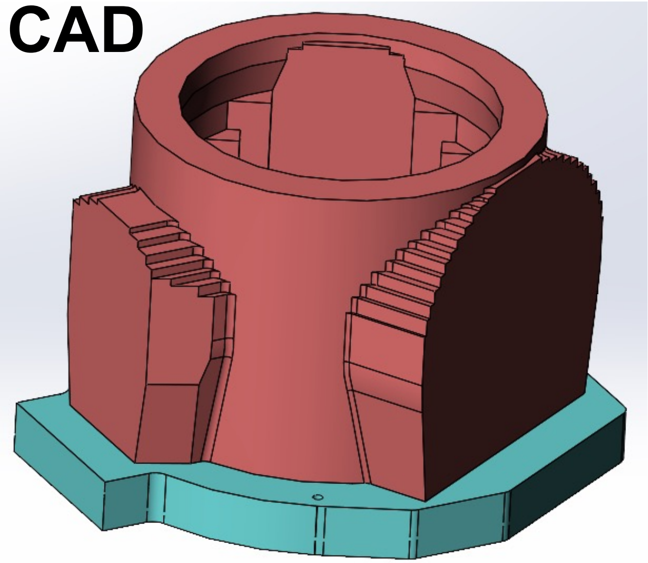
Inconel 625

- 3 days to print each (2 parts)
- 1600lb of Inconel 625
- 16 lb/h per arm (total 48 lb/h) max
- *Unbeatable lead time* – Time to acquire wire then print was shorter than getting build plates of 625

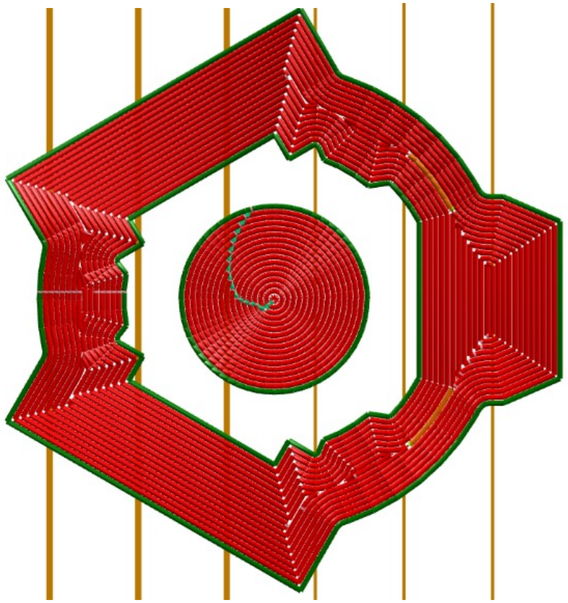


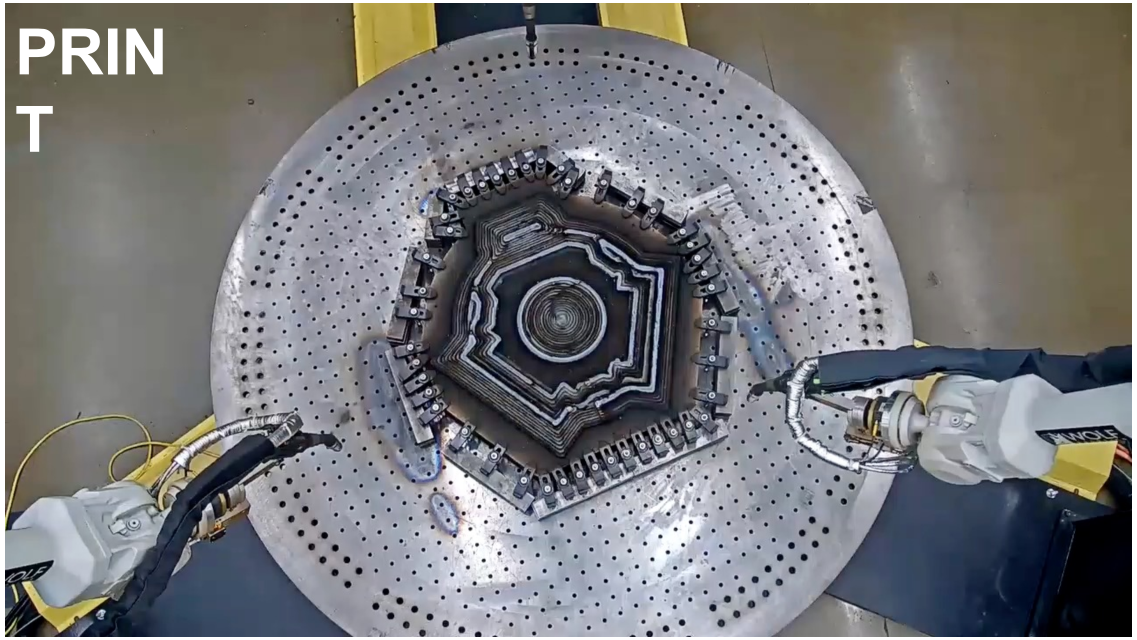
Large Valve Body – Huntington Ingalls

- 2500lb CuNi casting replacement
- 18lb/h per arm (54lb/h total)



Toolpath





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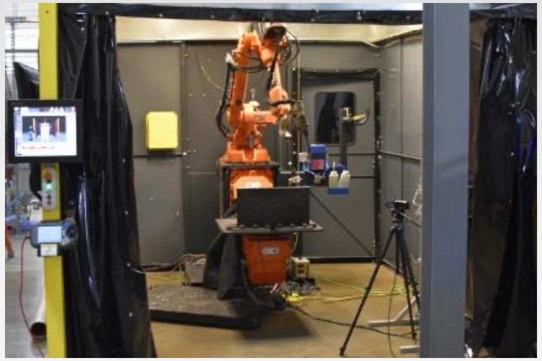
Large-scale Metal Systems at ORNL/MDF

Lincoln Wire Arc Cells 1 and 2

- ABB 6DOF arms and 2DOF positioners
- Lincoln Electric Welders

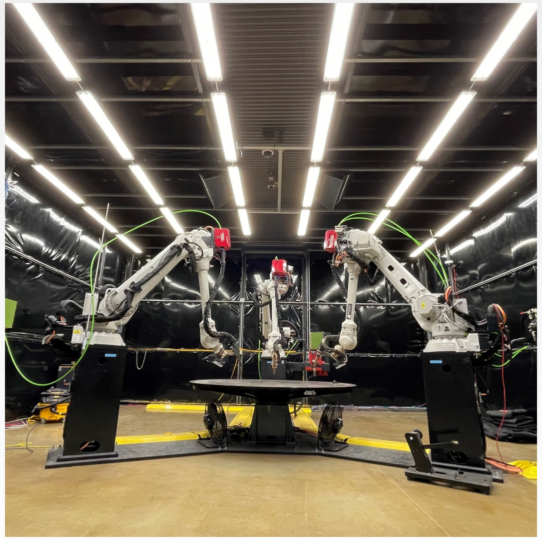


Lincoln Laser

- ABB 6DOF arm and 2DOF positioner
- Lincoln Electric hot wire system
- Coherent CW fiber laser

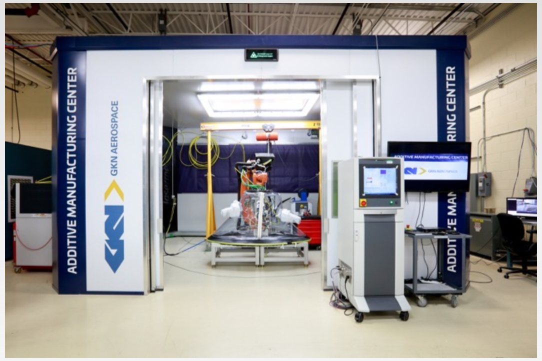
MedUSA

- 3x ABB 6DOF arms and1DOF table
- 3x Lincoln Electric welders
- Multi-agent, coordinated deposition



GKN Cells 1 and 2

- Kuka 6DOF arms and 2DOF positioner
- Laser-wire

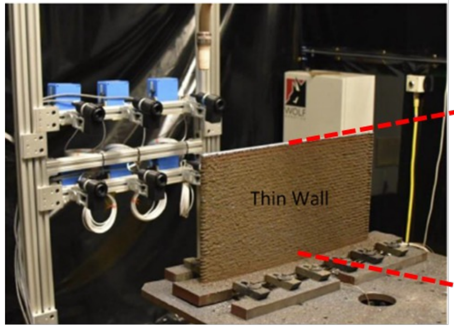


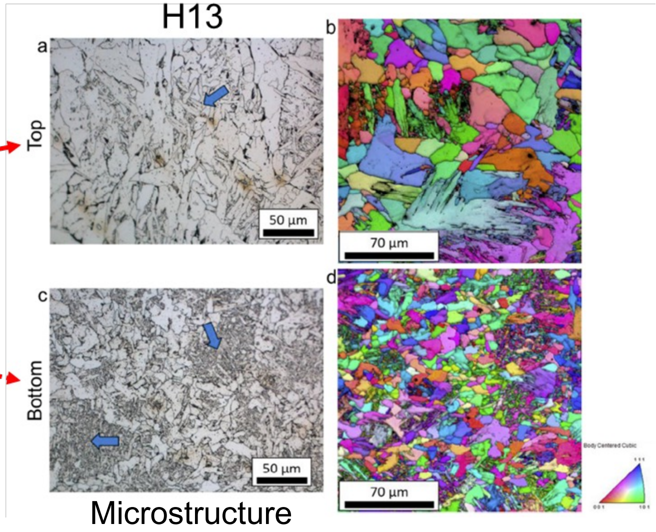
Modeling and Simulation for Large-Scale Metal AM

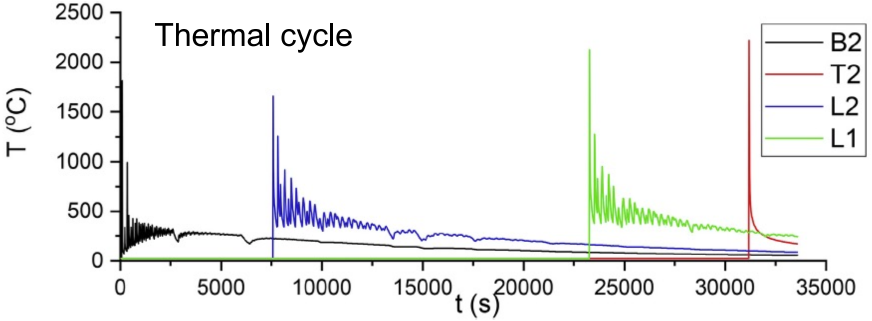
Model Demonstration

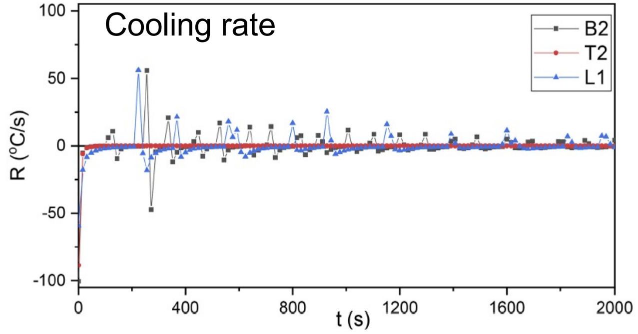
S. Simunovic et al., Process Modeling and Validation for Metal Big Area Additive Manufacturing, NAFEMS World Congress, Stockholm, Sweden, 2017, pp.1-17.

Thermal Cycle and Microstructure









Hu, Xiaohua, Andrzej Nycz, Yousub Lee, et al., Materials Science and Engineering: A 761 (2019): 138057.

Property Evaluation of Materials Printed

Type	Material	Chemistry (base), wt.%	Status	Tensile	Charpy	Fatigue	Hardness	Microstructure
Low alloy steel	L59		AP	✓	✓			
	LA100	Fe-1.9Ni-0.5Mo-1.6Mn-0.5Si-0.03Ti-0.05C	AP	✓	✓	✓	✓	✓
			HT	✓	✓	✓	✓	✓
	3Cr bainitic steel	Fe-3Cr-3W-0.2V-0.1Ta-0.4Mn-0.16Si-0.1C	AP	✓	✓		✓	✓
Ferritic-martensitic	410	Fe-12.5Cr	AP				✓	
	410NiMo	Fe-12Cr-5Ni-0.5Mo	AP	✓	✓		✓	
			HT	✓	✓		✓	
PH steel	17-4PH (630)	Fe-17Cr-4Ni-4Cu-0.3Nb	HT	✓	✓		✓	
Maraging	Maraging 250	Fe-18.5Ni-7.5Co-4.8Mo-0.4Ti	HT	✓	✓		✓	
	Maraging 300	Fe-18.5Ni-9.0Co-4.8Mo-0.6Ti	HT	✓	✓		✓	
Stainless steels	316L	Fe-19Cr-12Ni-2.5Mo	AP	✓	✓		✓	
	316LMn		AP		✓		✓	
	316LSi		AP					
Invar	CF36	Fe-36Ni	AP	✓	✓			In progress
Tool steels	Dievar	Fe-5Cr-2.3Mo-0.6V-0.5Mn-0.2Si-0.35C	AP					✓
	943 (Weld Mold)	Fe-3.25Cr-1.4Mo-0.25V-0.7Mn-0.35Si-0.55C	AP					✓
Ni-base alloy	625		AP		✓		✓	
	718		AP	✓	✓		✓	In progress
			HT					
Cu-base alloy	Cu-Ni	70Cu-30Ni	AP	✓	✓			In progress
	Ni-Al-Bronze		AP	✓	✓			In progress

AP: as-printed
HT: heat-treated

Working with Oak Ridge National Laboratory

Mechanisms for enhancing, developing & improving your idea/technology

	User Agreement (non proprietary)	**Strategic Partnership Project** (Proprietary)	**Cooperative Research & Development Agreement**
Length of engagement	Up to 12 months.	As defined by agreement.	Longer-term basis of a year or more.
Cost to Company	No cost.	Full cost recovery.	Cost-share required.
Intellectual Property Rights	Each party owns its own inventions. Jointly developed inventions will be jointly owned.	Companies own intellectual property made or created using corporate funds as a result of these engagements.	Companies own inventions they make during the collaboration and have an option to negotiate an exclusive license in a specific field of use to inventions made by ORNL.
Protection of Generated Information	Information generated is publicly available.	Companies paying for services with corporate funds can treat all generated data as their proprietary information.	Commercially valuable information generated under a CRADA may be protected for up to 5 years, depending on funding source.

ORNL Partnerships. Final reports of select industry collaborations.

Collaboration through Ma2jic consortium

- Industry-University-MDF/ORNL(DOE) collaboration (IUCRC extension)
- Membership-based
  - **Graduate student**(s) with Faculty supervision working on a project
  - MDF/ORNL support **funded by DOE** (no cost)
  - Access to **all Ma2jic** consortium R&D **results**
- Workflow
  - **R&D** project
  - University partner
  - Project approval
  - Project execution (Industry-University-MDF/ORNL)
- Membership 55$k/year
- Ask for details

Conclusions

- Tooling **attractive** for large scale metal
- **Augment** rather than replace
- **High accuracy** - smart strategy for path control
- **Near net shape**
- **Low-cost** feedstock
- **Ready** today

Acknowledgments

- Dream Team
  - Lonnie Love, Suresh Babu, Chris Masuo, Alex Arbogast, Mark Noakes, Andrzej Nycz, Derek Vaughan, Luke Meyer, William Carter, Sugata Roy, Alex Walters, Jacob Fowler, Rachel Harris, Steven Patrick, Matthew Puryear, Trey Mingee, Srdjan Simunovic, Ben Shassere,
  - Lincoln Electric: Johnathan Paul (JP), Jason Flamm, Mark Schaub, Steve Peters, Andrew Peters, Brad Barnhard, Badri Narayanan, Tom Mathews…

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Questions?

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- Visitors welcome
- Industrial partners
- Students, interns, co-ops, Post BS, MS, PostDocs