Additive Manufacturing:
Code Implications of Making Components from Weld Metal

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What's in a Name: Additive Manufacturing or Welding?

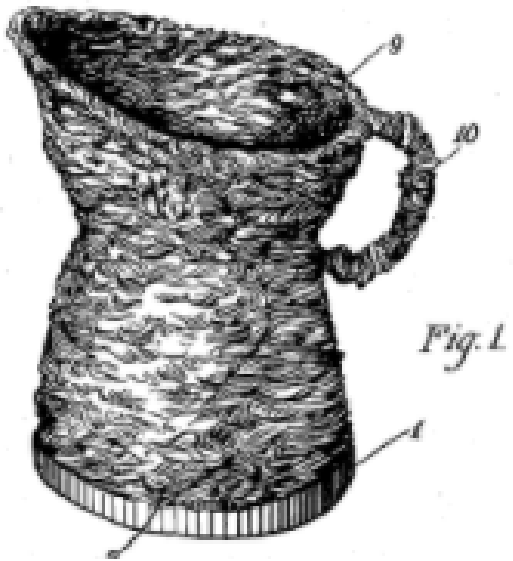
April 14, 1925.

1,533,300

R. BAKER

METHOD OF MAKING DECORATIVE ARTICLES

Filed Nov. 12, 1920



- Additive Manufacturing - parts are "builds"
  - 3D Printing
  - DED (directed energy deposition)
  - WAAM (wire arc additive manufacturing)
- Welding – parts are "weld metal"
  - Shape Welding, Weld Metal Buildup
  - Most commonly GMAW
  - Some hot wire laser, GTAW and Electron Beam

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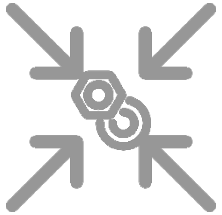
» See Melfi Video 1

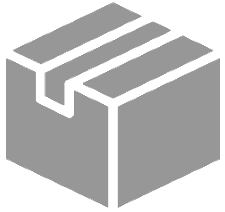
Key Benefits of Additive Manufacturing

Reduce
Lead times



Design
Freedom

Fast & Functional
Prototypes



Mitigate Supply
Chain Risk

Less
Waste

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Best Uses for Weld Metal AM

Value Lever	Use Case	Example
Reduce Cycle Time	Large castings and forgings Repair parts Functional prototypes	
Reduce Material Waste	High chip removal Low yield components High cost materials	
High Tooling or Fabrication Cost	Large or complex tools Complex casting molds & cores	
Simplify Joining	Tubular connections Multiple joints or weldments Modularized, in-the-field joining	
Enhance Performance	Light-weighted components Shape modifications Design flexibility	

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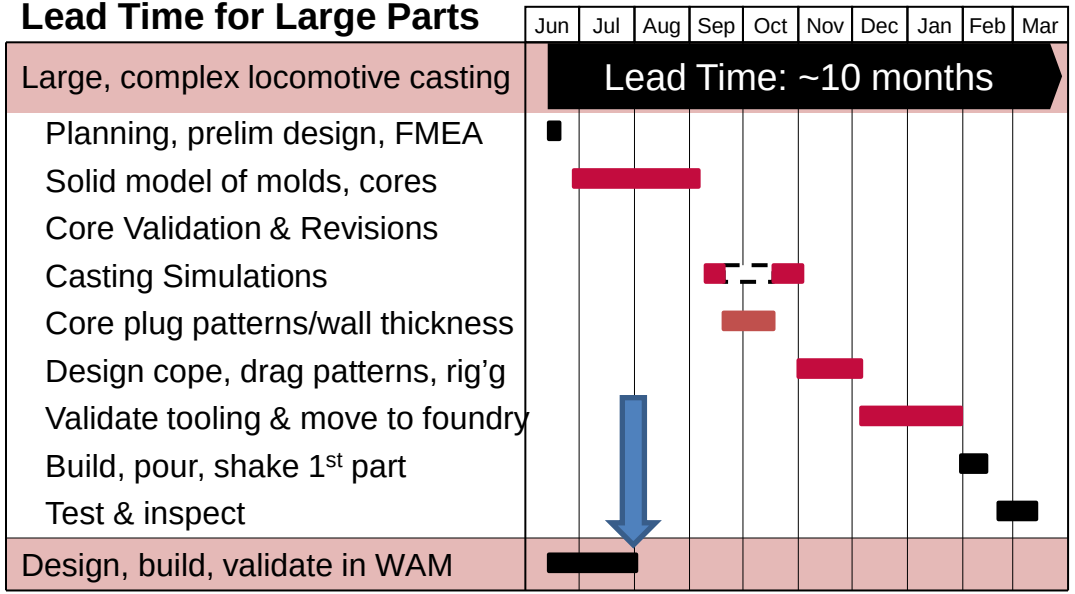
Rapid Turnaround

- No tooling required (design & produce)
- Digital design and production are fundamentally integrated
  - From CAD to part same day!
- No castings ‘cartel’

Lead Time for Large Parts



Casting-Specific Activities

Component: Integrated Front End
Weight: 2,300 lbs.
Dimensions: 50” x 55” x 40”
(Courtesy GE Corporate Research)

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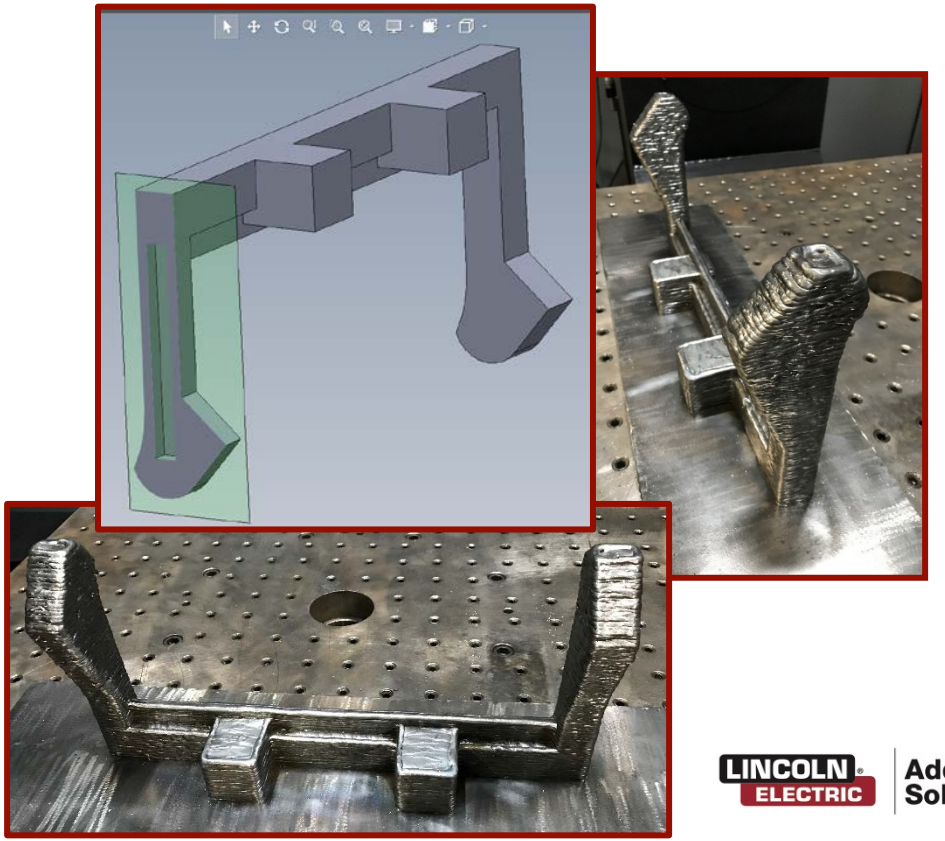
Replace obsolete parts

- Critical component of production machinery
- Obsolete and no longer available
- Challenging to fabricate ➔ high cost / long lead time
- Designed and printed < 3 days
- Created 3D CAD from old 2D drawings
- Printed with built in fluid channel



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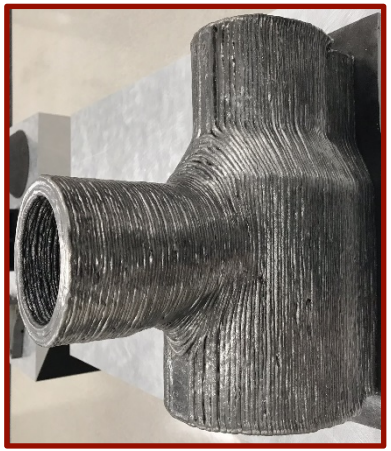
Prototypes to validate new valve design

- **Challenges**
  - Long lead times for steel castings; 6 months for first casting, 3 months for revised castings
  - Typically three design iterations (more than 1 year manufacturing time)
- **Solutions**
  - Modified design for Additive
  - Printed & ready for machining in less than a week
  - Total cost similar to one-off castings



Tooling for Aerospace Composites

- **Carbon Fiber Lay-up Molds**
  - Facesheet comes in direct contact with carbon fiber
    - Thermal profile
    - Dimensionally stable
    - Vacuum integrity
- **Boeing-Wisk Invar mold**
  - Collaborative design between Boeing R&T and Lincoln
  - Total length: 10ft
  - 3D printed sub-structure
- Tooling as large as 3,100 lbs

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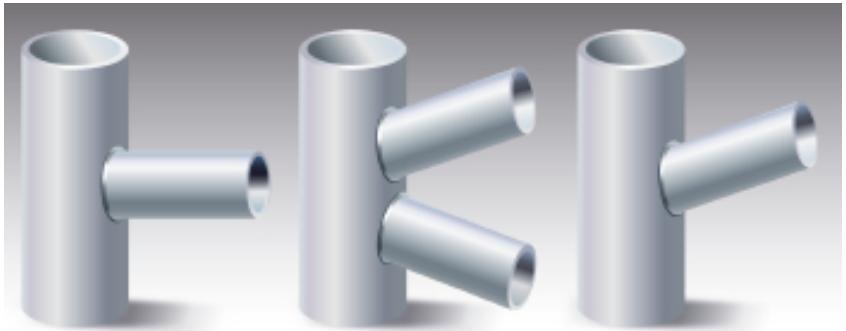
Structural Connections Video

» See Melfi Video 2

Offshore TKY Joints

- Joint development with Ohio State University's Center for Design and Manufacturing Excellence
- Challenges
  - "Blind" complex welds
  - Stress risers at weld joints ➔ fatigue failure



THE OHIO STATE UNIVERSITY

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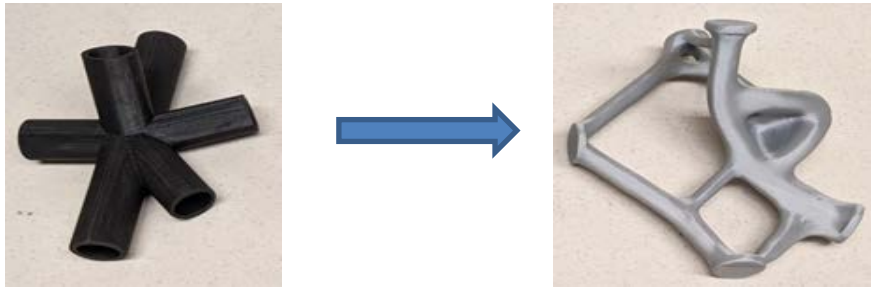
OSU Topology Optimization



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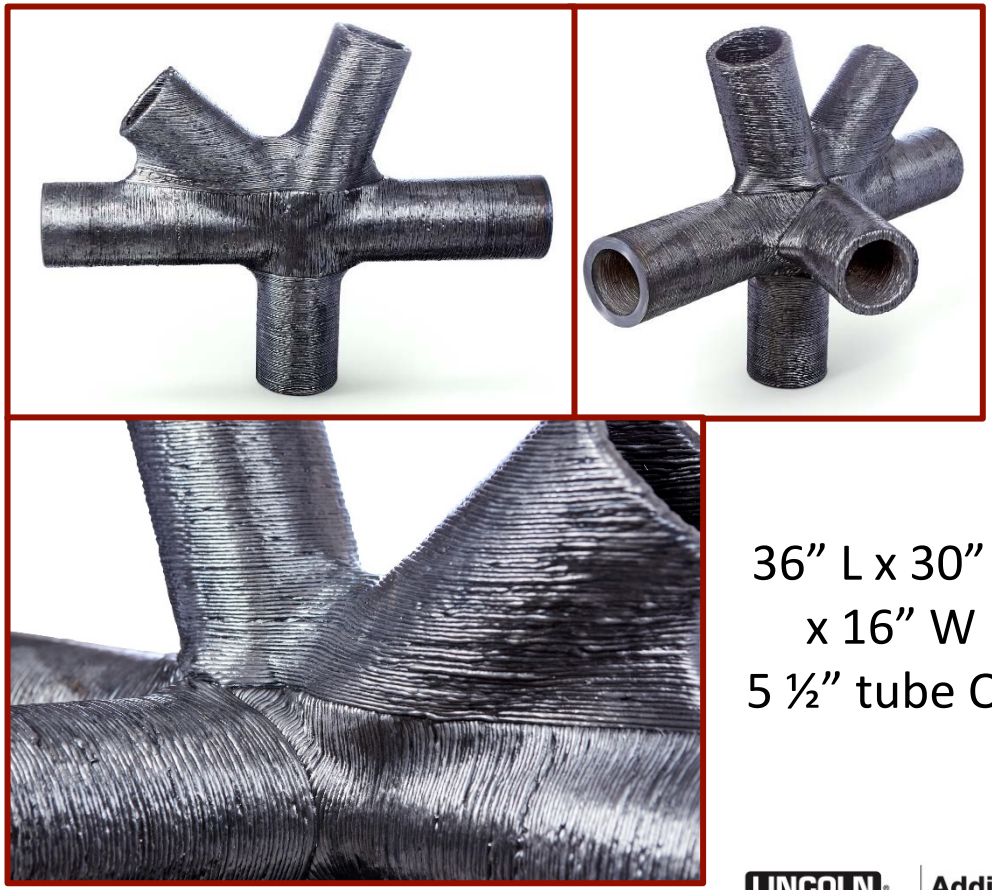
Offshore TKY joints

- Traditional TKY modified and enhanced for Additive
  - Hollow cylinders
  - Intersections gusseted
  - Eliminated sharp transitions
- Takes advantage of the ability to print non-planar layers “in space”



36” L x 30” H
x 16” W
5 ½” tube OD

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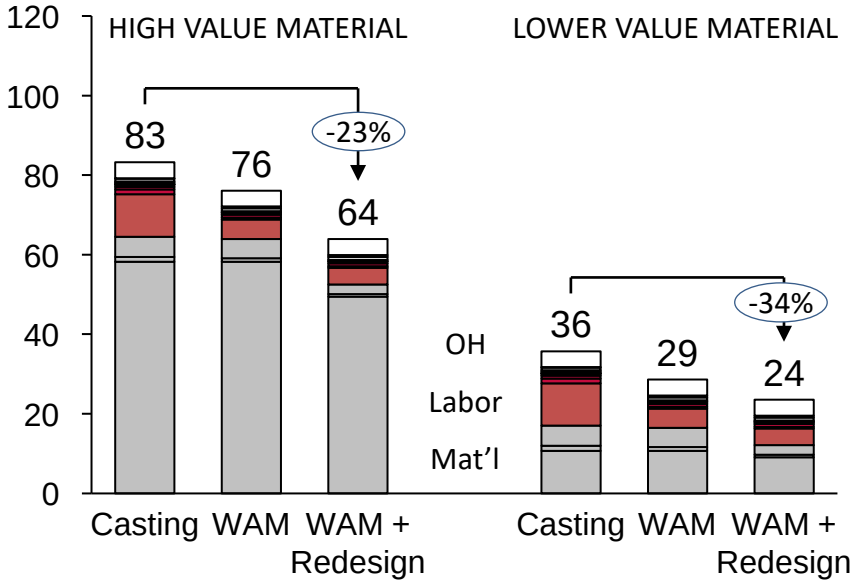
Of High Interest: Castings Conversion

Use Case: WAM for on-demand direct production of large castings (rotating machinery example).

- **Problem:** Complex systems often require challenging assembly of large components.
- **Castings Classification:** Expendable mold castings such as sand and investment castings best suited to WAM.
- **Materials:** Steels, stainless steel, aluminum, nickel-alloys and bronze.
- **Geometry:** Enormous castings possible; wall thicknesses can range from 1/8” to several inches, even within the same part; opposing channels, and radiating geometries are possible.
- **Benefits:** In addition to reductions in lead time, cost and performance advantages demonstrated by WAM over cast components.

Total System Cost to User, Complex Assembly
($000s)



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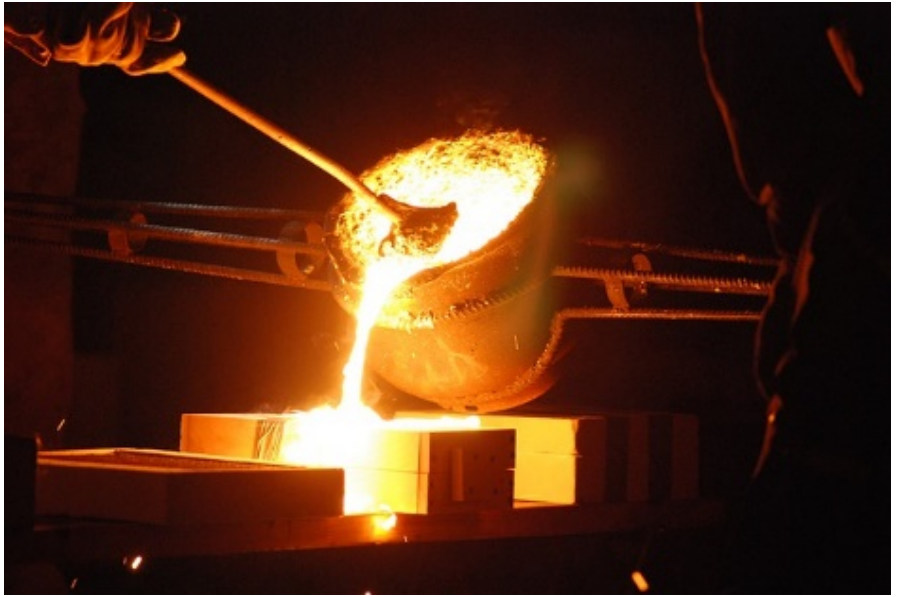
So, What's the Big Deal???

- Weld "buildup" rules exist in Section IX
- In the '70s it was hard to get castings or forgings
  - Large blocks were made from weld metal and then machined
  - Welded with SAW or even strip overlay (still in service)
- No BPV rules for how castings, forgings, pipe or plate are made



Section IX Actions

- Designs are already out there using “weld metal AM” parts
- Pressure from industry for Section IX to establish rules
  - Often from sectors outside BPV
- An enormous amount of data was available for GMAW
- The first code case was written exclusive to GMAW
- Review and Comment ballot was sent to Construction Codes

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Rules for Making Items from Weld Metal

- GMAW Section IX Code Case was approved in April
- Uses a bracketed qualification approach
  - Qualify the lowest and highest cooling rates that will be used in production
  - Qualify thin and thick sections, if both will be used in production
  - Tension, impact, composition and bend tests are required
  - Mechanical testing in the “worst-case” direction (Z-direction)
- The balance of rules essentially follow Section IX

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Parts can be made, but can they be used?

- The code case is already in use in non-BPV applications
- No material listing exists in Section II
  - An outside (ASTM, EN, etc.) specification is needed to establish a material in Section II
- Sections III and VIII are considering equivalence rules
  - Replacement for castings should be simple
  - Replacement for plate, pipe and forgings should be possible

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What about inservice repairs. . .

The components are very WELDABLE !!

Questions / Discussion

more information and cool videos at: https://additive.lincolnelectric.com