Field of 3D Dreams
Implementation of Additive Manufacturing in the Shipyard

NSRP All Panel Meeting March 24, 2021

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Agenda

• Presenter & Background
• Theme -Objective
• Industry AM
• Collaboration GD 3D Printing Team & NSRP
• Project Execution (DMAIC TOOLS)
  • Current State and wastes
  • New Tech selection and new process development
  • Future State
  • Traditional V AM examples
  • Savings: Cost and Cycle Time Compares
• Take-Aways
• Maturity
• Questions?
Theme- Objective

• Introduce Additive Manufacturing (AM) technology into the shipyard and engineering processes.
• Lay down a standard entry level process to adopt AM technology that significantly reduces labor, material costs, and cycle time in the following areas of focus
  • Design prototypes
  • Small jigs and fixtures
  • Metrology and maintenance spares.
Why Not Ships Parts?

- NASSCO and Industry Process constraints
- Require qualification and approval by Regulatory Bodies such as ABS and Navy
- Risk of part failure of load bearing parts in ships service
- Conflict with traditional industry process, steel construction, welding, blasting and paint
- Ship environment, with regard to corrosion, temperature, fatigue over time
- The interface connections were unproven bonding, friction fitting, or mechanical fitting, the only likely integration methods with existing ships parts.
- Secondary challenges, with regard to Navy parts, which are traditional copy and paste designs
- Finally Ship parts are REALLY BIG!
Additive manufacturing (AM) popularly known as 3D printing, is a technique that builds objects layer by layer from a CAD model design using materials such as polymers, metals and composites.

This technology has been available since the late 80’s.
AM offers great possibilities to accelerate design innovation, compress supply chains, reduce material and energy usage, waste and reduce cost.

Shipyards in general have been slow to adopt the technology.

- This is due mainly to part volume, size, material, environment and regulatory approval
Collaboration

• NASSCO has been a member of the GD 3D Printing Team since its introduction in 2014
  - NASSCO
  - Electric Boat
  - Bath Iron Works
  - Gulfstream
  - Jet Aviation
  - European Land Sys.
  - Land Systems
  - Mission Systems
  - Information Tech.

• This Project in part was funded by the National Shipbuilding and Research Program (NSRP)
  - Selected as a panel project in 2020
  - Outcome of sharing how AM could be adopted across the USA shipbuilding community in the chosen area of focus.
Project Approach  Lean Tools: DMAIC

• **DMAIC** *(an acronym for Define, Measure, Analyze, Improve and Control)* refers to a data-driven improvement cycle used for improving, optimizing and stabilizing business processes and designs.

• The DMAIC improvement cycle is the core tool used to drive **Six Sigma** projects. However, DMAIC is not exclusive to Six Sigma and *can be used as the framework for other improvement applications*.
Problem Statement (condensed)

The design and procurement of small jigs/ tools/ fixtures/ prototypes/ templates/ mock ups and maintenance part substitutions using traditional methods is costly and turnaround times from order to receipt were excessive.

Objective Statement (condensed)

The goal is to develop a clear methodology and a proven process that incorporates in-house additive manufacturing capability to develop cost effective and timely solutions in the target areas where opportunities exist on current commercial and navy contracts.

Scope Boundaries (clarification)

Applicable additive solutions to be in plastic/polymer that satisfies customers

Metrics

Labor hrs, material cost and cycle time

Depts Involved

Metrology, Layout Department, Engineering and Weld Services,

Timeframe

Year 2020
DMAIC: Define Phase

- Develop SIPOC (Engineering)
  - Process to create prototypes

[SIPOC Diagram]

- Suppliers:
  - Outfitting
  - Hull
  - IDNA
  - Government/ABS

- Input:
  - Detailed Drawings

- Process:
  - Prototype creation process in Engineering

- Output:
  - model

- Customers:
  - Outfitting
  - Hull
  - IDNA
  - Government/ABS

- Steps:
  1. Review Drawings or given information
  2. Plan out how to build model and of what material
  3. Gather/Purchase Supplies/Tools
  4. Measure out and create all parts to model
  5. Put model together piece by piece
**DMAIC: Measure Phase:** Process to secure metrology and weld service spares (Shipyard) sim for prototypes (Engineering)

- Develop Current State Map (Shipyard and Engineering)
  - And Value Analysis

**Current State Summary**
- 9 Functional Disciplines
- Value Added Steps= 11
- Non Value Added Steps= 5
- Best Case Elapsed Days= 10 DAYS
- Worst Case Elapsed Days= 23 DAYS

- Value Added Activities
  - PO filled and approvals
  - Place order
  - Fill order
  - Delivery of parts

- Non Value Added Activities
  - Research
  - Inspection
  - Storage
  - Other administration
DMAIC Measure Phase: Summary of the 3 Predominant Processes

• **Summary: Elapsed Days, Functional Disciplines, VA/NVA Steps**

<table>
<thead>
<tr>
<th>Process</th>
<th>Range of Elapsed Days</th>
<th>Count of Functional Disciplines</th>
<th>Count of VA, NVA Steps</th>
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</thead>
<tbody>
<tr>
<td>1. Source metrology spares from a vendor (1 and 3 Sim) (Shipyard and Engineering)</td>
<td>10-23</td>
<td>9</td>
<td>11,5</td>
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<tr>
<td>2. Source Prototypes/Mock Ups (Engineering)</td>
<td>12-22</td>
<td>4</td>
<td>12,2</td>
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<tr>
<td>3. Source production support/marketing parts from a vendor (1 and 3 similar) (Engineering and Shipyard)</td>
<td>10-23</td>
<td>9</td>
<td>11,5</td>
</tr>
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DMAIC Analyze Phase 3D Printing Group

- Role of the 3D Printing Group To give the eyes to the Enterprise to see
  - Cross BU (around 9 BU members 40+ participants on monthly calls)
  - NASSCO member since 2014 (Eng Reps Only)
  - 2017 Manufacturing Engineering and Operations joined with Engineering

- Benefits to NASSCO
  - Group collaboration (Accelerated Learning Curve)
    - Understanding of AM practical examples
    - Understanding of AM technologies
    - Available and affordable equipment
    - Expertise to draw from to provide direction, and get our “toe in the water”
DMAIC Analyze Phase  AM Benefits

- Benefits of Additive (and Industry research)
  - Reduces cost (shipyard and engineering)
  - Reduces the amount of steps in a process (shipyard and engineering)
  - Reduces the amount of steps in a prototyping or mock up process (functional / early engineering)
  - Reduces production delays when existing fixtures break (shipyard)
  - Reduces the amount of steps in a sourcing process (shipyard and engineering)
  - Reduces the need for manual assembly
  - Reduces material waste
  - Reduces weight
  - Reduces Lean Wastes (See later Reference 8 LEAN WASTES “DOWNTIME”) (shipyard and engineering)
  - Reduces inventory (low volumes versus traditional minimum order sizes)
  - Reduces the amount of distinct parts
  - Reduces the range of materials required
  - Reduction of Lead Times internally or externally (shipyard and engineering)
  - Flexibility to design solutions to meet customer needs (shipyard and engineering)
  - Flexibility to support “one off” solutions that suppliers did not offer a specific solution without long design cycles, minimum batches with hi-set up costs (shipyard and engineering)
DMAIC Analyze Phase  Why Not Ships Parts

• NASSCO and Industry Process constraints
  • Require qualification and approval by Regulatory Bodies such as ABS and Navy
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  • Secondary challenges, with regard to Navy parts, which are traditional copy and paste designs
NASSCO Business Environment (Constraints) affecting AM technology integration

- Capital expenditure was limited, initial investment had to be very modest in AM
- Senior Management was not fully educated about the potential and capabilities of additive manufacturing, hence tentative “buy-in” and not a longer term investment plan yet considered
- There weren’t too many implemented additive solutions in the Marine Industry to tout as meaningful examples with cost savings data or proven business benefits that could motivate rapid change
- Non-existent R&D capability in the shipyard, this was going to be the Team’s second or third job by a handful of enthusiastic Team members who were interested in the potential and could provide a meaningful case to propose to Management to get equipment funding
- NASSCO In house engineers had non-existent design development experience in 3D printing design, modeling and technology. Shipbuilding designs tend contract to contract to be a “copy and paste” preferred approach with reluctance to significantly change designs without a good deal of hand wringing and significant investment in shipyard design resources.
DMAIC Analyze Phase

• NASSCO Business Environment (Constraints) affecting AM technology integration
  The NASSCO shipyard facility due to a favorable year round climate is open air for the most part, which would preclude the use of large-scale 3D printing capabilities unless built into clean environment. CAP-Ex Investment was not prioritized which precluded the case for larger build volumes and potential for metal additive manufacture

• Risk averse mentality, typically we would adopt a crawl before walk before run philosophy on new technology

• MRP system tools are 40 years old, with considerable number of patches to make them run and interface with other business tools
Analyze Phase

- NASSCO Business Environment (Constraints) affecting AM technology integration
- “Never the right time” to introduce part re-designs due to long initial Contract design lead times, following short design rollovers from Hull to Hull, mixed with in-process manufacture of current Contracts and Hulls.
- Supply Chain buyers at NASSCO did not have Additive Manufacturing experience or confidence to changeover to nontraditional solutions to part procurement at short notice
- Reluctance to move away from traditional and familiar buyer/supplier partnerships
- Existing Certification authorities ABS, NAVSEA, USCG had no real run time with AM to issue design rules, material certification, quality standards or testing requirements to the marine industry
- There wasn’t a “3D Printing Playbook” to follow, which added to risk concerns and conservative investment upfront
Analyze Phase

- GEMBA “the real place” Shipyard and Engineering Walks by the Team
  - To identify AM opportunities
  - Two hours weekly over six weeks overall (Shipyard and Engineering)
- Six primary production areas in the shipyard, Fabrication, Sub-Assembly, Assembly, Block Outfitting, Grand Blocking, Onboard, Machine Shop and Weld Service shops
- Many potential opportunities for AM surfaced
  - Potential quick wins
  - To see results and get internal customer feedback immediately.
Analyze Phase

• GEMBA “the real place” Shipyard and Engineering Walks by the Team (Traditional Parts) – Potential AM Solutions
IMPROVE PHASE   Steps

• Brainstorm of possible solutions
  • What was our rationale for the 3D Pro plus printers, number of, other equipment, material selection? (MV & Yard) (Wes)

• Value Stream Map future State
  • Supporting the key metrics to dramatically reduce elapsed days, eliminate functional disciplines involved and reduce NVA activities

• Prioritize Solutions (PICK Chart)
  • Understand which potential solutions with respect to AM (3D) introduction equating solutions as easy or difficulty to implement and payback as low or high for those that were able to be implemented by the team. additionally those items deemed as KILL (parking lot for future consideration)

• Create Improvement Plan
  • Describe those activities undertaken to introduce and indoctrinate the process
    • Describes the user request process and workflow to provide AM solutions
  • Include lessons learned on installation, training . lessons learned and examples of AM solutions
01/2017 - Joined GD Additive Group
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06/2019 - Purchased 2 Raise 3D Pro 2 Plus FDM Printers
09/2019 - Printed Reflector Base to Dial in Printer Settings on Production Printer
11/2019 - Won 2 Additive NSRP Panel Projects

03/2018 - 1st GD Annual Additive Meeting
03/2019 - 2nd GD Annual Additive Meeting
09/2019 - Printed ESB Voids to Dial in Printer Settings on MV Printer
10/2020 – Awarded NSRP RA Project
We started at the basic level of deciding which type of technology we wanted/which technology the company could afford:

- PLA – (Polylactic Acid) Fused Deposition – Nozzle lays thin layers of heated material
- SLA – (Stereo lithography) Material is laser cured in layers
- SLS/DMLS – Selective Laser Sintering, typically used for metal
- SLM – Selective Laser Melting, typically used for metal

SLS and SLM were ruled out due to their expensive cost.

PLA chosen over SLA as we could print multiple parts faster while avoiding dealing with the curing process time and mess associated SLA.

SLA will probably be a future printing technology we look at purchasing specifically for printing fine detailed parts/models.
  - It was not necessary to begin our journey with, and PLA was more versatile with the material types it is capable of printing.
A comparison matrix was developed for the top PLA printers to aid decision making: as shown in Table 1 below:

<table>
<thead>
<tr>
<th>Model</th>
<th>Cost</th>
<th>Technology</th>
<th>Extruder</th>
<th>Max Layer Resolution (microns)</th>
<th>Max Print Area (LxWxH) (cm)</th>
<th>Print Materials</th>
<th>Option Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Makerbot Replicator +</td>
<td>$2,499</td>
<td>Fused Deposition</td>
<td>Single</td>
<td>100</td>
<td>29.5x19.5x16.5</td>
<td>PLA</td>
<td>7</td>
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<tr>
<td>Makerbot Replicator Z18</td>
<td>$6,499</td>
<td>Fused Deposition</td>
<td>Double</td>
<td>100</td>
<td>30.0x30.5x45.7</td>
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<td>5</td>
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<tr>
<td>Fusion 3 F410</td>
<td>$4,599</td>
<td>Fused Filament</td>
<td>Single</td>
<td>20</td>
<td>35.5x35.5x31.5</td>
<td>11+</td>
<td>6</td>
</tr>
<tr>
<td>Raise3D Pro2</td>
<td>$3,999</td>
<td>Fused Filament</td>
<td>Double</td>
<td>20</td>
<td>28x30.5x30</td>
<td>15</td>
<td>2</td>
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<tr>
<td>Raise3D Pro2 Plus</td>
<td>$5,999</td>
<td>Fused Filament</td>
<td>Double</td>
<td>20</td>
<td>28x30.5x60.5</td>
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<td>1</td>
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<tr>
<td>Ultimaker 3 Extended</td>
<td>$4,295</td>
<td>Fused Filament</td>
<td>Double</td>
<td>20</td>
<td>19.7x21.5x30</td>
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<tr>
<td>Ultimaker S5</td>
<td>$5,995</td>
<td>Fused Filament</td>
<td>Double</td>
<td>20</td>
<td>33x24x30</td>
<td>10</td>
<td>3</td>
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</table>

- The price point of all printers was relatively the same.
- Key features desired resulted in choice of 2 of the Raise3d Pro2 Plus Printers
- Double extruder to be able to print two materials at once. This would allow for support material to be used if we needed it for a specific part.
  - Largest build volume available to print large parts or large batches.
USED PICK Chart to categorize IMPROVEMENT Ideas for inclusion or not in the FUTURE STATE PROCESS

- X-Axis = Difficulty
- Y-Axis = Payoff
Title: Future State Process to Submit, Evaluate, Design and Manufacture an AM Requested Part for Metrology/Mock Up/Prototype & Maintenance Spares

Future State Process Map
A user request form process was developed and communicated.

It is intended (outstanding action to utilize JIRA workflow tools) to provide a more robust workflow process and the ability

Collect metrics and build a library of parts for re-ordering

Contribute to our Continuous Improvement culture, crediting the user/originator capturing benefits and savings where appropriate
AM Examples

Engineering

- **Flounder Plate**
  3D printed a to scale flounder plate which was used by rigging engineers to determine feasibility of a unique design. The unique was designed for a specific lift and turn scenario, and the riggers needed to ensure it would properly attach to their designated pick location.
• Modular Outfitting Unit
  Printed for outfitting to gauge how it will be installed in the ship to replace current system.
AM Examples  Engineering

- Welding School Training Block
  T-AO Block used by the welding school for training purposes.

T-AO Block 224 (Inverted)

Sub-Assembly Breakdown

Internal View
AM Examples  Engineering

Future Modular Concept Design

Module Example

Additional Capabilities

- Modular Concept Design
  Early stage concept ship used by marketing department to promote future capabilities.

Print Design Spiral Process
• **T-AO Expansion Joint Connection**
  T-AO Expansion Joint Connection is pivotal to the ship’s operation and difficult to envision how it ties into surrounding structure. The 3D printed version was used to help with its installation.
AM Examples Engineering

• T-AO Expansion Joint Video
**AM Examples** Covid 19

- **Sanitary Door Handle**

Each handle cost $100 to purchase online, but only $3 to 3D print.

- **Sanitary Door Handle**
  Sanitary door handle that allows the user to open the door without touching the handle and spreading germs or viruses.
AM Examples  Covid 19

• Connectors and protectors for Plexiglas virus barriers
AM Examples  COVID19

• Mask Connector- TPU PolyFlex
AM Examples  Covid 19

• Mask extender clip
AM Examples   Production

- **Reflector Base**
  - Used with metrology equipment to hold SMRs (spherical mounted reflector). Using 3D printing we can create our own designs and replicate the originals for a small fraction of the original cost while maintaining an acceptable accuracy.
AM Examples  Production

Spare part for Crane

- Original pieces is discontinued
- Nonconductive material is required
- Original price: 10 hours machine shop + material
- 3D Printed: $1.00 (printing time 2 hrs.)
AM Examples

Production

Socket Jig

- **Socket Jig**
  The purpose of the Jig is to accurately align the SMR at the center of the socket. There are a lot of sockets so the faster we can align it the better. With 3D printing we can create and customize jigs to make our process faster.

3D printed

- Accuracy ±0.5mm
- Cost: $1.50 (printing time 2 hrs.)
- Faster alignment
- Easy to reproduce/replace
AM Examples  Production

• Welding machine spare part (screw cap)

Before (Real)  After (Printed)

Cost per piece: $28.25  Cost per piece: $0.8
Quantity per year: 100  Design cost: 4 hrs.
Only one manufacture  Printing time: 1 hr.
AM Examples

• Spare part for Chalk Line
Shell Margin Jig

- Nylon accessory to measure Shell margin.
- Design to fit the combination square
- Adjustable height
- Can be held with one hand
AM Examples

Production

Adapter for SMR holder

Telescopic holder for SMR

Process Improvement Initiatives
Telescopic holder for SMR - Adan Rodriguez

- Old Process
- New Process

- During metrology surveys, we need to place the reflector at locations that are hard or unsafe to reach.
- Normally the solution is to attach the reflector to a broom stick (using an adapter).
- The problems:
  - No broomsticks around.
  - Not very professional.
  - Carrying a broom stick around is not very practical.

- To use a telescopic holder, it is small / lightweight enough to be inside our backpacks all the time.
  - Has a better grip
  - It’s easy to carry
  - No need to look around for broomsticks

GENERAL DYNAMICS
NASSCO
*Used to prove to ABS that the space and stuffing for the cables is the right size. Different sizes and depths need to be check, this new tool is design to cover all of them.
AM Examples  Production

Disto offset accessory
CONTROL PHASE

- Parts and Orders
  - Steady adoption 2020/21
• 145 AM User requests made, 502 AM Parts made
• Savings
  • In both Shipyard and Engineering locations on average
    • Traditional Manufactured Matl + Labor $128k
    • Additive Manufactured: Matl + Labor = $51k
    • Savings $77k (60%)
    • Cycle Time reduced from 2-3 weeks down to 1 week
      • Would be 2-3 days if we had full time AM resources
    • 97% reduction in Material $ Costs
    • 48% reduction in labor hours
    • 50-66% reduction in Cycle Time
CONTROL PHASE

- COMMUNICATION PLAN (TO SHARE, COLLABORATE and ENGAGE)
  - Communication Mode/Description
  - Roadshow (with Hourly/Staff)
  - Screensaver, Publications
  - “Business” Card (AM)
  - Outbriefs, Forums
  - Method of Delivery
    - Meeting, Articles, Posters, Presentations
    - Virtual, In person, Email,
  - Frequency/Target Date
    - Q1, Q2, Q3 etc
  - Goal/Objective
  - Communication, Status, Share Potential, Feedback
  - Developer/Owner
  - AM Team
  - Audience/Customer
  - Shopfloor, Eng, Other Depts, Management, GD Enterprise & NSRP

### ADDITIVE MANUFACTURING (AM) COMMUNICATION PLAN

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Next Steps and Take-Aways

- Next Steps
- NASSCO and Current USA Shipbuilding Industry Initiatives
- NASSCO is looking to eventually migrate AM to create real ship parts in the future. In 2020
- NASSCO led an NSRP panel project revolving around scaling up 3D printing capabilities with metal printing. This project successfully increased the deposition rate of aluminum material. Future projects will focus on higher yielding materials.
- NASSCO is working with the NAVY and ABS to establish those future projects which will ultimately lead to developing rules, guides, and regulations for printing shipboard parts.
- THIS IS JUST a START..... (Goal is Metal/Polymer Ships Parts!!)
Next Steps and Take-Aways

• Take Aways
• Adopt new technology in a small scale in areas you can control at the onset
• Take advantage of “process experts” to assist your journey
• Off the shelf solutions are often available and meet most needs with minimum financial investment
• The implication of 3D printed solutions is enormous well beyond this entry level project
• Maturity
  • Mature (small scale effort but implemented)
Questions?

GOT 3D?

- **What is 3D Printing?**
  3D printing starts with a virtual 3D model that is transformed into a solid form one layer at a time. Each layer is built on top of the layer before, creating a solid form in plastic. It’s just like laying weld beads but more controlled to build up an accurate form.

- **What Shipyard Applications?**
  We have made weld machine parts, crane parts, electrician gauges, and all kinds of accuracy control jigs and fixtures.

- **Traditional Material**
  Hard, soft, and flexible plastics. Come see.

Let’s Have Your 3D Printing Ideas
Do you have a part, tool, jig, template, or shape we can create? We can print it for you in plastic!

3D Examples

Let us help make your idea a reality!

Contact:
Accuracy Control Office
Engineering ext. 8822 or 8686
Adan Rodriguez
Kelly Christiansen
Wes Downs