Cost Estimating Challenges in Additive Manufacturing

International Cost Estimating and Analysis Association

Southern California Chapter Workshop

El Segundo, CA

Joe Bauer – PRICE Systems, LLC

Pat Malone – MCR, LLC

9 September 2015

Additive Manufacturing in the News….

Army Eyes 3-D Printed Food For Soldiers

NOVEMBER 04, 2014 3:25 AM ET

AARTI SHAHANI

3D Printing Is Transforming the Supply Chain

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Will 3-D Printing Revolutionize Medicine

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INNOVATION

3-D printing takes flight. Literally.

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Lockheed Martin is using 3-D printers to manufacture tools used to construct its F-35 Joint Strike Fighter.

From mechanical parts to pieces of jewelry, 3-D printing is all the rage. And now the new technology is taking flight. Literally.

Bethesda-based Lockheed Martin is using 3-D printers to manufacture tools used to construct its F-35 Joint Strike Fighter, according to Defense One.

"There are no 3-D-printed parts flying on F-35 today, [but] we use hundreds of 3-D-printed tools for F-35 manufacturing such as bracket locators and drill templates," Lockheed spokesman Mark Johnson said, according to the report. "We are working on 3-D printing of parts, but they are still a few years in the future."

Brings new meaning to the term "next-generation fighter," doesn't it?

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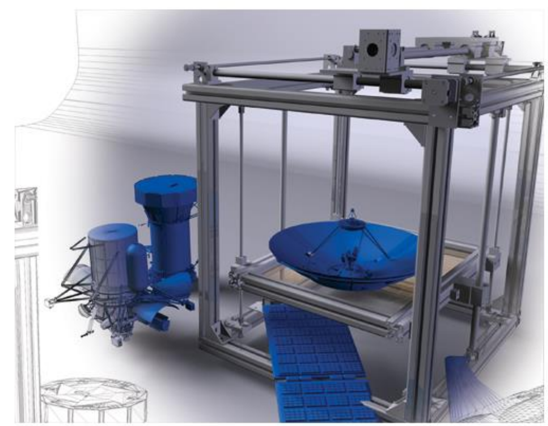
3D Printing Promises to Revolutionize Defense, Aerospace Industries

March 2014

By Yasmin Tadjdeh



New manufacturing processes, such as 3D printing, have gained worldwide attention for creating everything from entire houses to guns. While used for many novel purposes, the defense and aerospace industry is eyeing it as a way to cut costs and improve efficiency.

Three-D printing shakes up the traditional process of manufacturing — which takes raw materials and subtracts from it by whittling or drilling — by adding layers of a substance, often a polymer or metal, to create an object. The method, which is also known as additive manufacturing, only requires a user to download a blueprint to the printer. Because the process uses fewer materials, it can save companies money as well as allow them to create parts on the fly, according to industry technologists.

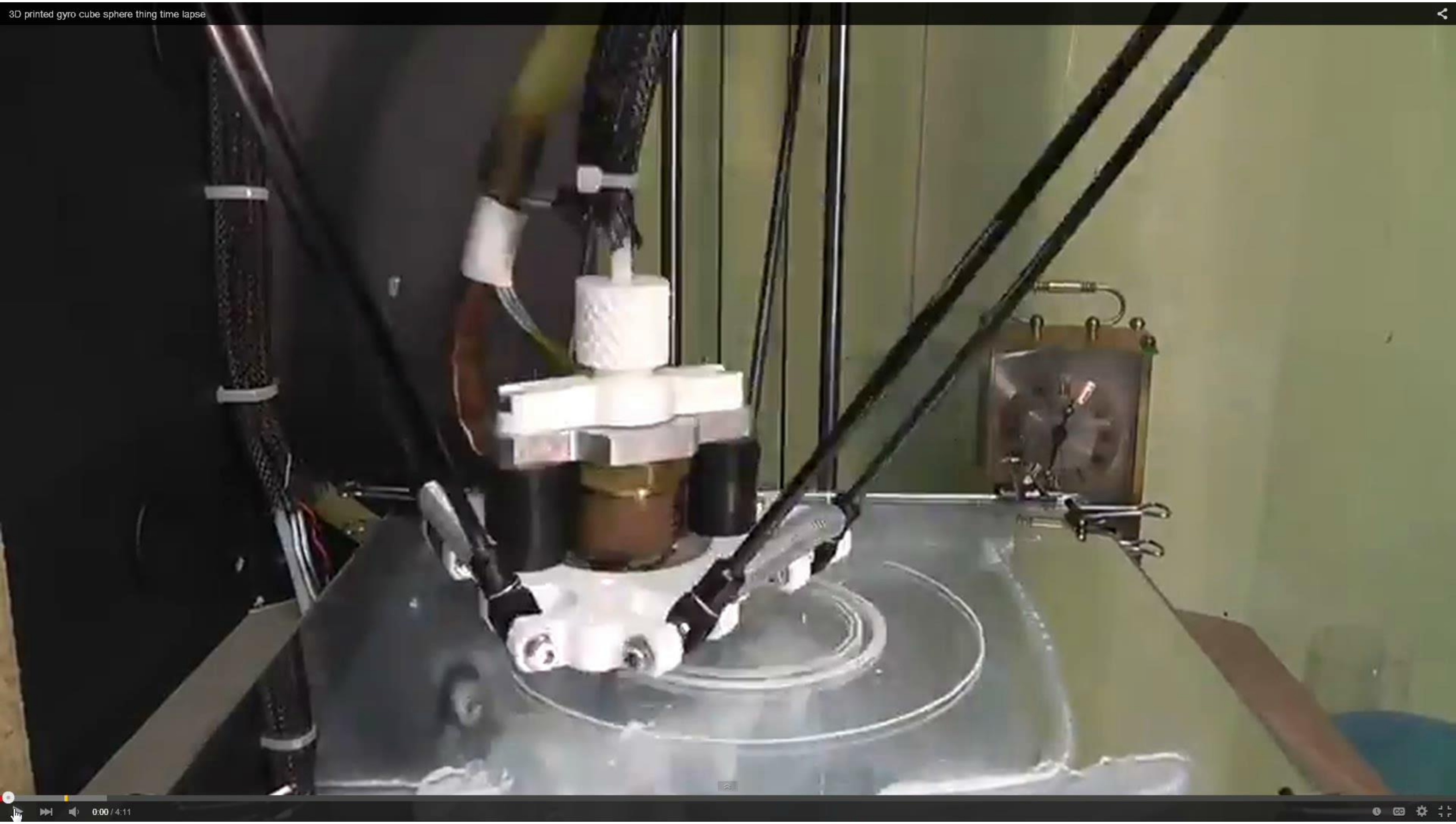
Introduction

- Our Challenge
- AM in Aerospace and Defense
- Cost Modeling Implications of AM
- Conclusions and Future Study
- References
- The Authors

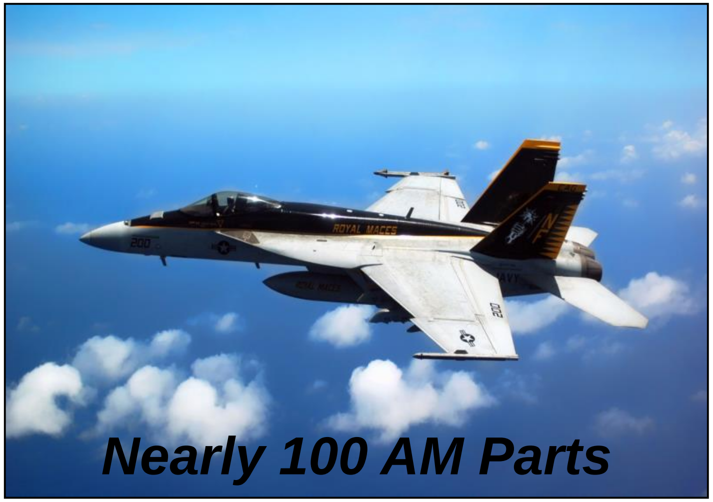
Our Challenge

- Additive Manufacturing (AM) is a new paradigm
- Cost modeling using traditional parametric estimating methods may not accurately predict AM part costs
- Current cost estimating relationships are primarily based on Traditional Manufacturing (TM) processes
- Modeling adjustments are required to accurately predict AM costs

First, a video...



Additive Manufacturing in A&D



Nearly 100 AM Parts

Nearly 1000 AM Parts

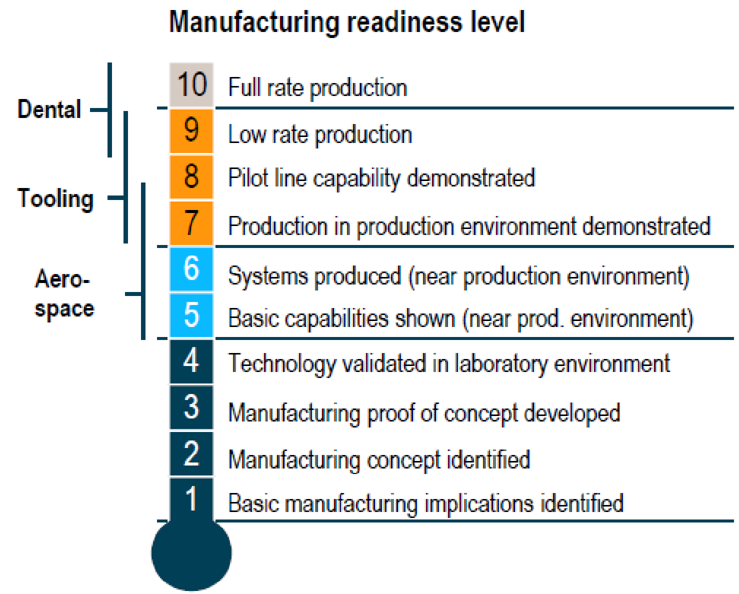
- Allows for complex geometry
- Mitigates diminishing manufacturing sources
- Reduces logistics footprints
- Supports lighter hardware solutions
- Reduces assembly and integration

Additive Manufacturing - History

- Dates back almost 150 years
  - "Cut and Stack" building layer by layer
- First Successful AM process with powder deposition circa 1972
- Many patents filed in 1980's
  - Key enabler – CAD
  - Solid Modeling
- Today, there are more than seven technology types
  - Technology types are driven by proprietary solutions
  - Manufacturers typically trademark technology and material blends
  - More technologies expected before industry consolidation/maturity

Additive Manufacturing – Current State

- Medical / dental applications fully entrenched
- Emerging support for limited production of non-critical components and rapid prototyping
- Obstacles to higher MRL:
  - Process control
  - Airworthiness certification



5.5 oz. steel belt buckle

2.5 oz. titanium belt buckle

Source: Roland Berger_ Additive Manufacturing_20131129

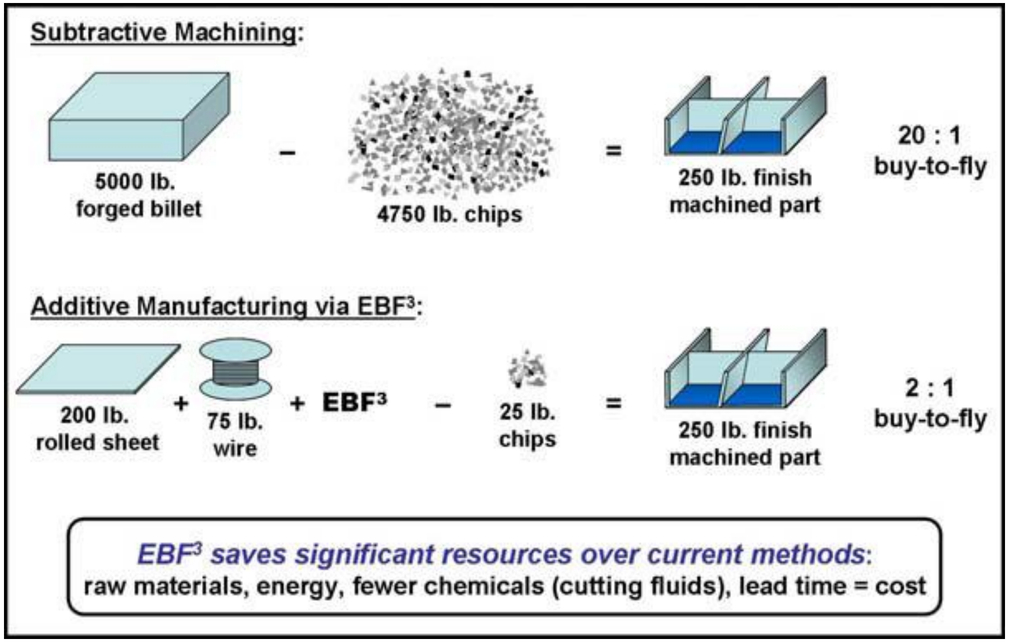
Technologies

- Aerospace and Defense applications primarily use:
  - SLS – Lightweight complex metal parts
  - 3D-Printing – Routine but low quantity plastic parts

	Technology	Enabler
1	Stereolithography	3D vison
2	CAD and Solid Modeling	Mathematical Models
3	Machine Language Interpretation	Digital translation to 3D Layering
4	Selective laser sintering	Advanced materials
5	Sheet lamination	Complex laminates
6	Material extrusion	Layer Fusing
7	3-D printing	Broad array of applications
8	Traditional Post Processing	Surface finishing/Quality Inspections

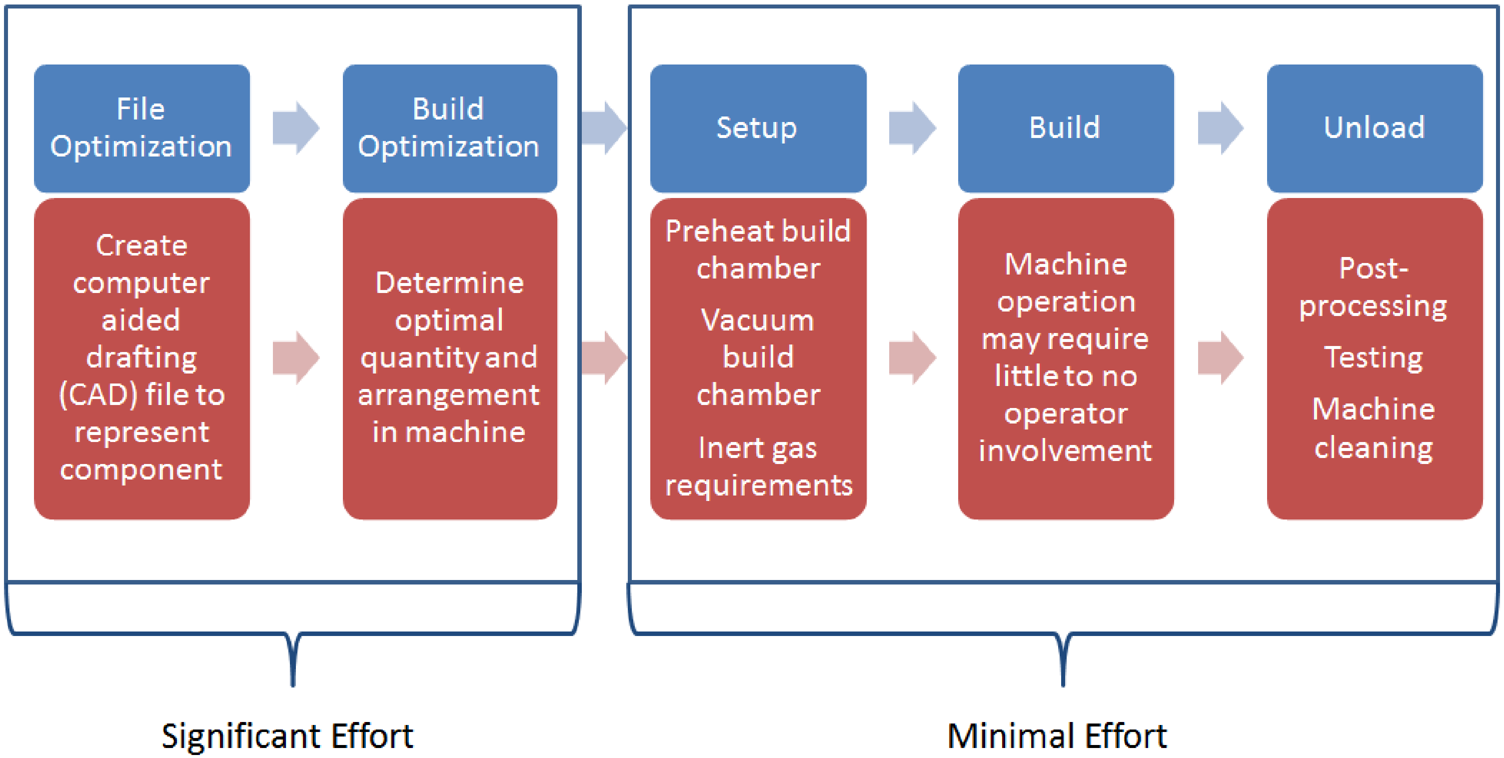
Technology Advantages

- Rapid prototyping
- Minimal scrap or wasted material
- Higher complexity parts
- Lower part counts
- Diminishing sources recovery



Wing Assembly, Source: www.growit3d.com

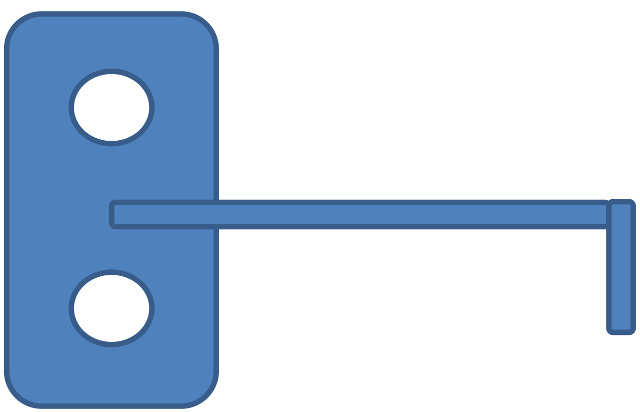
Typical Process Flow



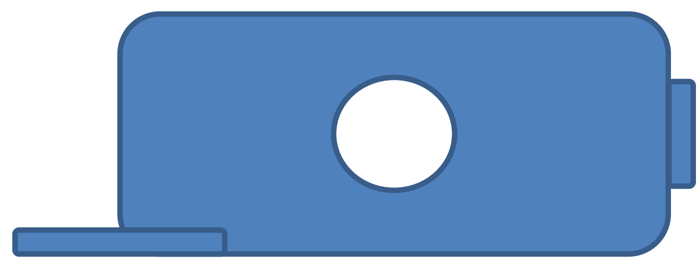
- Upfront design / build optimization supports the minimal effort during repeatability phase
- Processes vary based on technology, material, and machine

Case Study

- Small Ti-64 bracket used in military aircraft
- Slug Weight: 472 grams
- Final Weight: 40 grams
- Final Dimensions: 2.58 in x 2.13 in x 1.06 in
- Quantity: 3,000+

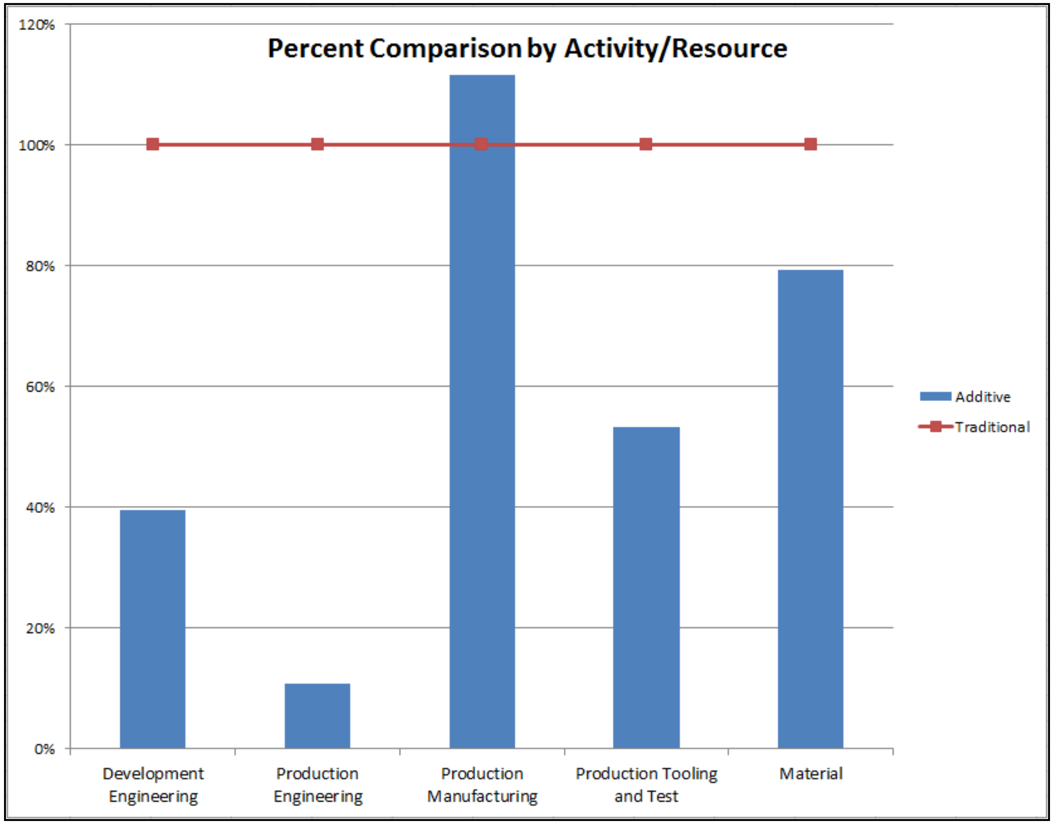


Top View



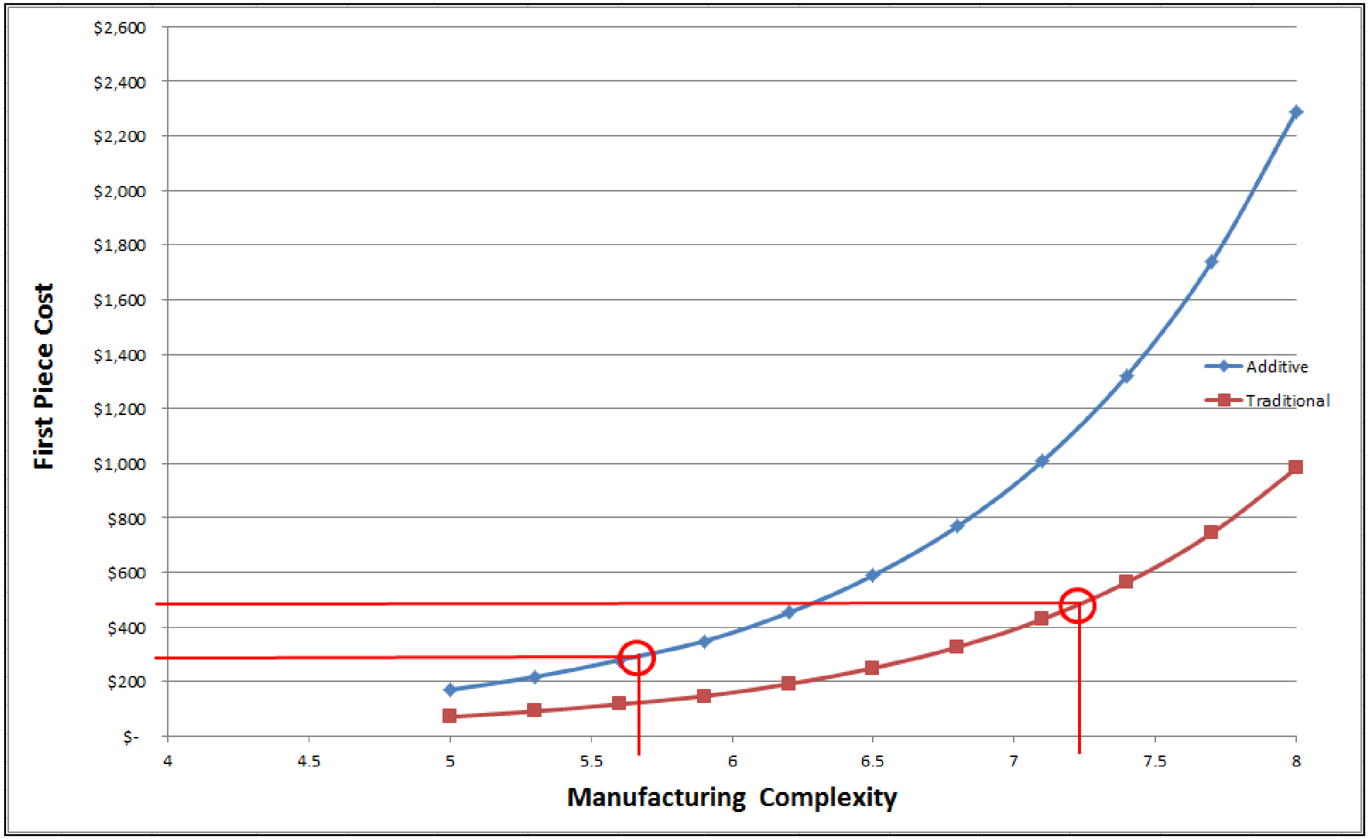
Side View

Cost Modeling Implications of AM



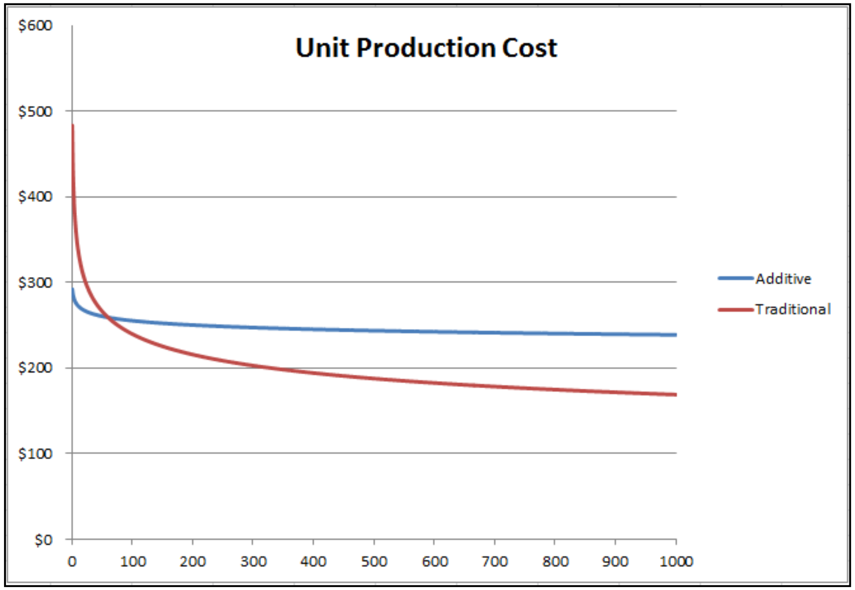
- Material cost up to 8x higher
- Material requirements 12% of TM bracket
- Program timeline shortened by 41%
- Non-recurring equipment cost may be amortized across other programs
- Activity multipliers and complexity factors must be validated in parametric models

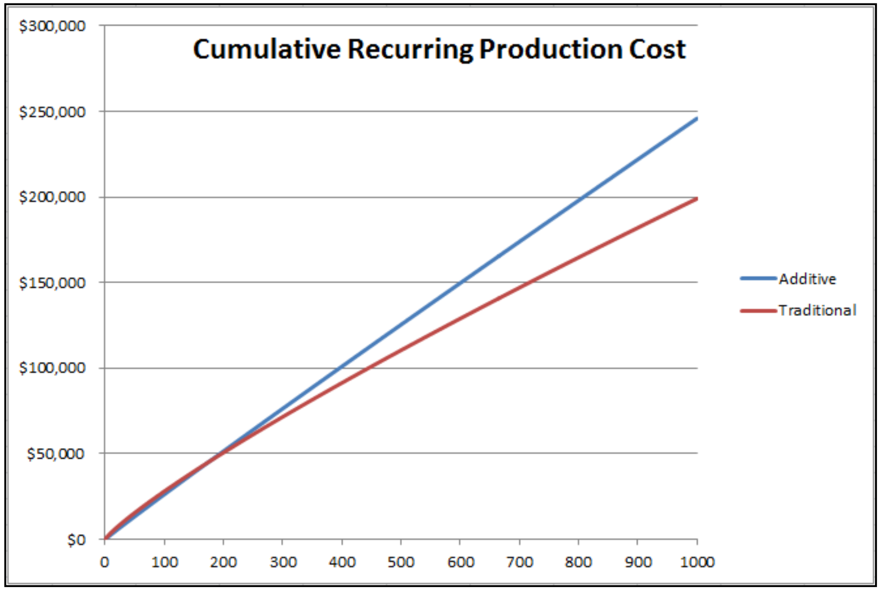
Cost Model Implications (cont.)



- First Piece Cost (T1) may be 40% less with AM processes due to markedly reduced manufacturing complexity of structural components

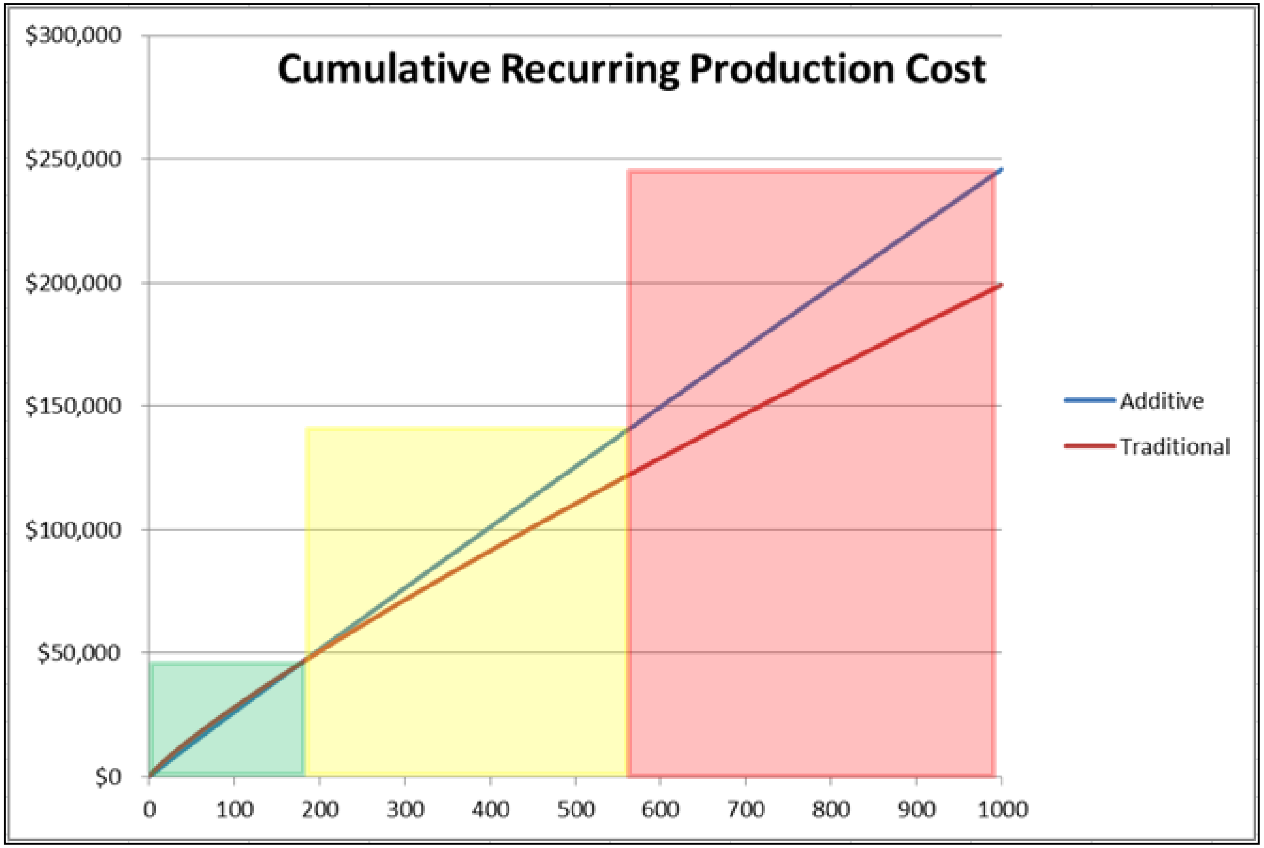
Cost Model Implications (cont.)





- While AM T1 is lower, it is a nearly constant recurring cost
- Higher quantity production runs may be cheaper using TM

Cost Model Implications (cont.)



- But…higher recurring costs may be offset by reduced schedule
  - Green: AM is favored
  - Yellow: TM cost is lower but AM may still be favored due to shorter schedule
  - Red: For larger production runs, TM may be the best alternative

Conclusions

- Additive processes and materials are continuously improving
- For short production runs of non-load bearing components, AM has the advantage in:
  - Material Requirements
  - Unit Production Cost
  - Schedule
- Adjust for the following inputs in parametric models:
  - Material Cost
  - Component Complexity
  - Manufacturing Process
  - Learning Curve

Additive Manufacturing – Future State

- More (and cheaper) material options
- Continued vertical integration of market
- Increase in quality, build rates and chamber volumes
- Process / technology standardization across industry
- Wider acceptance in A&D applications
- Common certification requirements

Recommendations for Future Study

Interlinking cogs made via additive layer manufacturing - as each piece is an unbroken whole with no joints or weak points, ALM enables the manufacture of incredibly strong, complex components

Source: University of Exeter, UK

- Review emerging materials and processes
- Establish databases for cost/technical/schedule parameters
- Research schedule impacts
- Update CERs for AM
- Make higher fidelity recommendations related to parametric cost modeling

Research Update

Current Research

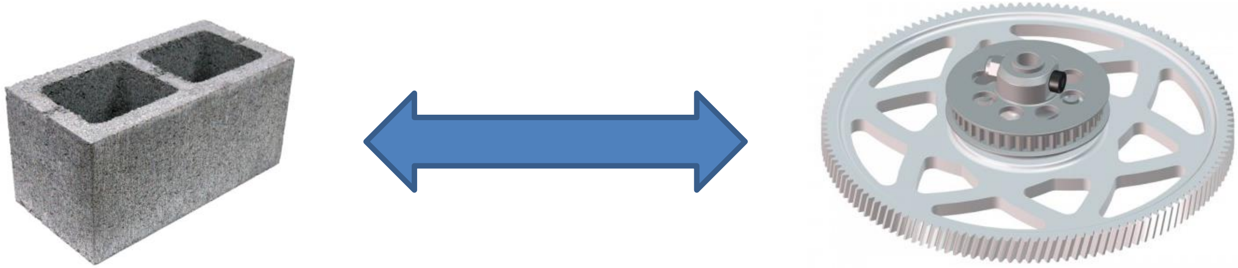
- Lehigh University (Pennsylvania)
  - Additive Manufacturing Department
  - Graduate Student research to identify cost drivers
  - Coordinating with AmericaMakes
- Air Force Research Laboratory (Wright-Patterson AFB)
  - Partnering with Wright State University in Dayton, Ohio
  - Identifying potential AM projects for low cost attritable UAVs
  - Research for next generation aircraft engine components
- Several "Build to Print" firms in Dayton area
  - Data collection
  - Model validation

Lehigh University

- Focusing on production effort
  - Machine / technology application
  - Machine build time
    - *Height*
    - *Quality*
    - *Geometry*
  - Material selection
  - Draft parametric model under development
- To Do
  - Validate model methodology with commercial manufacturers
  - Incorporate model(s) into TruePlanning®
  - Further val/ver of model results

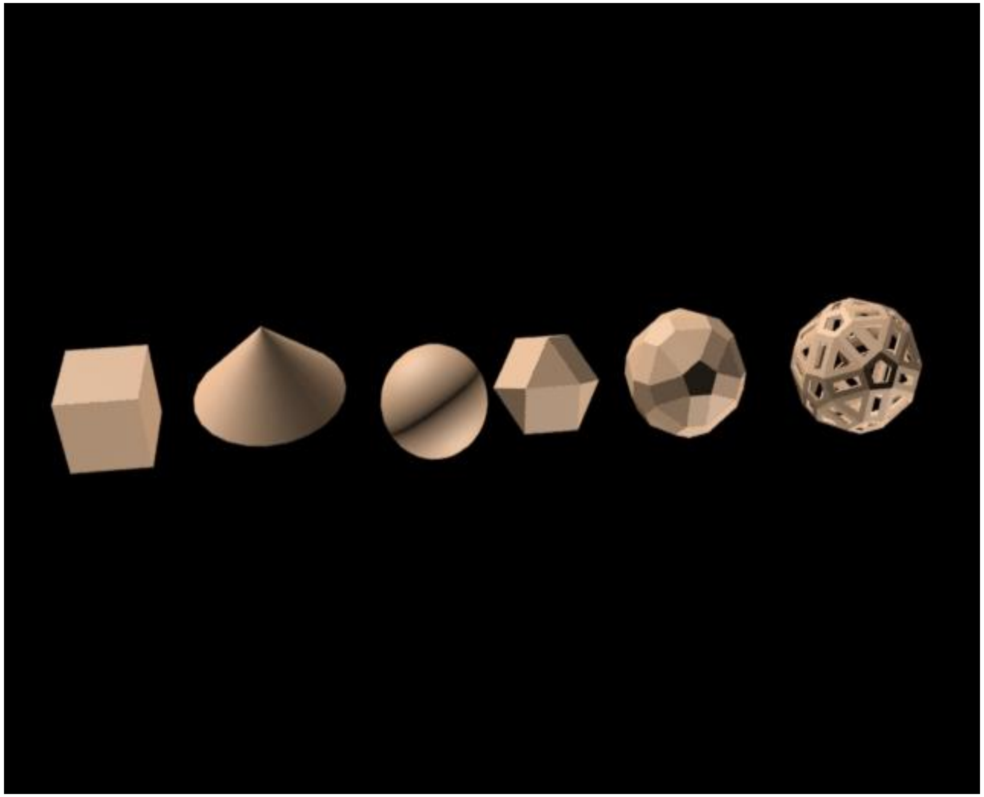
A Word on Complexity…

- In TruePlanning®, manufacturing complexity is a major cost driver in the hardware cost object, accounting for:
  - Manufacturing process
  - Functionality
  - Material type
  - Machinability of material
  - Number of parts
  - Amount of material removed during manufacturing process
  - Required precision
  - Complexity value represents a weight / cost curve



A Word on Complexity…

- In additive manufacturing, design complexity may not be a cost driver
- Cost drivers include
  - – Machine cost
  - – Material cost
  - – Build time
    - *Height*
    - *Quality or step size*
    - *Geometry*
  - – Need for post processing*
  - – Certification*
  - – Upfront design work*



*Research ongoing to validate some drivers

Questions?

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Backup

Top Benefits of Additive Manufacturing

- Reduces raw material requirements
- Reduces need for large inventory
- Reduces impact of diminishing manufacturing sources
- Reduced touch labor during manufacturing
- Reduces or eliminates assembly
- Ability to create complex internal geometries
- Ability to create lighter components
- Nearly eliminates impacts of engineering change orders
- Rapid prototyping reduces development time

Top Challenges of Additive Manufacturing

- High raw material cost
- High machine cost
- Certification for airborne environments
- Limited acceptance for mission critical components
- Lack of consistency of end item material properties
  - Between components during the same build
  - Between similar machines
  - Between different batches of raw material

Cost Implications of Additive Manufacturing

- High raw material cost, but less material required
- Mostly automated process with some manual post-processing requirements (grinding, polishing)
- Flat learning curve (~95%+)
- Typically lower first piece cost compared to TM
- Lower manufacturing complexity compared to machining, casting, other processes
- Little to no production engineering (ECOs)
- Higher cost of test/evaluation due to industry “novelty”
- Assembly/integration costs greatly reduced